Appendix A

Galveston Bay Regional Monitoring Protocols

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INTRODUCTION

1.1 BACKGROUND

The Clean Water Act as amended by the Water Quality Act of 1987 established the National Estuary Program (NEP) to promote long term planning and management in nationally significant estuaries threatened by pollution, development, or overuse. Section 320 of the Clean Water Act describes the establishment of a management conference in each estuary to develop a Comprehensive Conservation and Management Plan (CCMP). It also establishes requirements to monitor the effectiveness of actions taken pursuant to the plan.

The Galveston Bay National Estuary Program (GBNEP) was established under the authority of the Water Quality Act of 1987 to develop a CCMP for Galveston Bay. In 1990, work commenced to:

- Identify specific problems facing the Bay
- Compile bay-wide data and information to describe the status, trends, and probable causes related to the identified problems
- Create the CCMP document to enhance governance of the Bay at the ecosystem level.

GBNEP is accomplishing this work through a cooperative agreement between the U.S. Environmental Protection Agency (USEPA) Region 6 and the State of Texas (administered by the Texas Natural Resources Conservation Commission [TRNCC]). The structure of GBNEP reflects a strong commitment to consensus building among all Galveston Bay user groups, government agencies, and the public. This regional effort reflects thousands of hours of involvement by individuals who use, enjoy, or help manage this vital coastal resource.

GBNEP held a Regional Monitoring Conference in July 1992 to examine the need and feasibility of a regional monitoring program for the estuary (Tetra Tech, 1992). The participants included policy makers, resource managers, scientists, and representatives of public and commercial interest groups. From these discussions, a consensus was reached on the following points:

- A regional monitoring program is needed to improve our ability to effectively manage resources in the estuary

- Establishment and management of a technically sound regional monitoring program are feasible

- The details of the monitoring program should be designed by technical experts working with managers and decision makers.

Several monitoring programs are ongoing in the estuary. These programs are being conducted by federal, state, and local government agencies at an annual cost of nearly $8 million. Many of these monitoring programs use different field sampling and analytical methods, and collect data at different sampling locations and on different time scales. Furthermore, monitoring data are maintained at a number of locations, using different database management systems, and are stored in different formats. As a result of the diverse origins and purposes of these programs:

- Uncoordinated data collection efforts are executed

- Data from several monitoring efforts cannot be integrated (i.e., pooled) because
  - sampling or analytical methods are incompatible or
  - sampling locations or times are incongruous

- Data analyses are severely delayed because data are not readily accessible or require significant time and cost to translate into a usable format.

Participants of the Regional Monitoring Conference agreed that a coordinated regional monitoring program would increase the efficiency of monitoring efforts and enhance the usefulness of monitoring data for all persons responsible for managing the bay's resources.

1.2 APPROACH

This is the second of two documents prepared to address the requirement of the CCMP to develop a regional monitoring program for Galveston Bay. The first document (Tetra Tech, 1992) presented the plan or strategy for developing Galveston Bay's regional monitoring program. The development of this plan was based on the approach described in two recent documents: *Monitoring Guidance for the National Estuary Program* (USEPA, 1992) and *Managing Troubled Waters: The Role of Marine Environmental Monitoring* (NRC, 1990).

The first key step was defining resource management goals. Resource management goals describe the desired result of CCMP management actions and provide a point of reference from which managers can assess whether conditions in Galveston Bay are improving, declining, or remaining the same.

The next step is to specify the information needed to assess whether progress is being made toward achieving resource management goals. This information will be used to:

- Determine the status and trends in the condition of bay resources
- Assess the effectiveness of implemented CCMP management actions.

Monitoring objectives define what data and information the regional monitoring program will provide. A key contribution of the Regional Monitoring Plan was the specification of monitoring objectives to guide the design of Galveston Bay's regional monitoring program.

During April 1993, a series of technical workshops was held specifically to develop monitoring objectives for each of the five primary management topics (Water and sediment quality, Species population protection, Habitat protection, Freshwater inflow, and Public health protection). The purpose was to build upon the work described in GBNEP's characterization reports and to define monitoring objectives and corresponding monitoring variables.

Each of the five Primary Topics Task Forces met to discuss and reach a consensus on:

- Priority resource management goals

- Information needed to assess whether progress is being made toward achieving these goals

- Regional monitoring objectives

- Monitoring parameters.

Between June and August 1994, members of the Regional Monitoring Steering Committee convened several times in five Focus Groups (corresponding to Water Quality, Sediment Quality, Habitat Quality, Species Protection, and Public Health). Their aim was, in part, to further define monitoring parameters and recommend which of the existing monitoring protocols were most appropriate for inclusion in the Galveston Bay Regional Monitoring Program (GBRMP).

These parameters and protocols were chosen from the range of existing methods and parameters presently being used by the various agencies in their monitoring efforts within Galveston Bay estuary. The recommended protocols have been judged as best suited to support the Resource Management Objectives developed at the Regional Monitoring Conference.

The existing monitoring activities in Galveston Bay are discussed in detail in the *Galveston Bay Regional Monitoring Strategy* (Tetra Tech, 1994). A summary of these regional monitoring activities of each agency, showing: the number of sampling stations, their data collection activities, the parameters monitored, the analytical methods and detection limit, and the quality assurance/quality control (QA/QC) procedures was developed and circulated among the agency staff comprising the Monitoring Steering Committee (Table 1-1). This table represents the identified monitoring activities presently being undertaken in Galveston Bay. This summary of monitoring activities is the basis from which the recommended monitoring protocols, described later in this document, were selected by the Committee members.

Selection criteria (Table 1-2) were developed as a framework for comparison of existing methods. The selection criteria were also used to evaluate alternate methods. These are methods not presently being used, but have potential to:

- provide ancillary information for minimum extra cost or effort, or

- improve sample collection or analysis by decreasing the present levels of effort (e.g., using *in situ*, automatic measuring and recording probes with multi-parameter sensors).

These criteria will form the basis for an evaluation of the monitoring methods presently employed in Galveston Bay. This approach of incorporating existing monitoring elements has several inherent advantages. The criteria will be most useful in cases where different methods have been used by agencies to monitor the same or similar parameters (e.g., dissolved oxygen, total organic carbon).

Maintaining the comparability of data by recommending an existing method (or in some cases more than one method) will maximize the amount of previously collected data that can be incorporated into the regional monitoring effort. This historical data would not necessarily be as useful if new and different collection methods or analytical methods are followed.

Giving a high priority to the cost of collecting and analyzing data is pragmatic in this era of limited funding and overburdened budgets. This approach will maximize the amount of data that can be collected for a given monitoring budget. Cost efficiency is high when using

Table 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY

Summary of data collection activities, monitoring parameters, analytical methods, and quality assurance/quality control methods by the various agencies/organizations monitoring in Galveston Bay Estuary.

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
Texas Natural Resource Conservation Commission (TNRCC)	68 stations	Sediment:	All stations - Routine	EPA Methods (1,2)		TNRCC requires that a minimum of one water quality monitoring program and one water quality sampling program undergo a quality assurance review each fiscal year.
		Chemistry - Ekman dredge	Water:			
	243 sampling activities/year		Temperature, conductivity, pH			
		Benthic macroinvertebrates:	dissolved oxygen (DO), salinity			
(Kirkpatrick, 1994)		Peterson or Ekman dredge				
(TNRCC, 1993)			Conventional pollutants:			Projects:
(TWC, 1991)		Nekton:	Biochemical oxygen demand (BOD)	405.1	1 mg/l	- water quality monitoring field data notebook
(Twidwell, 1993 and 1994)		Collection techniques	Total suspended solids (TSS)	160.2	10 mg/l	- standard instrument calibration and notebook
(U.S EPA, 1983 and 1986)		- Hook and line, trotline	Oil and grease	413.1	5 mg/l	- flow measurement records
		- Throwline, handline	Fecal coliform (FC)			- fecal coliform bacteria analysis records
		- 20' minnow seine with 1/4" mesh				- biological sample analysis records
		- Gill nets	Nutrients:			- proper data and sample collection procedures
		- Fish traps	Orthophosphorus	365.2	0.01 mg/l	- quality assurance review follow-up
		- Trawl	Nitrite - N	354.1	0.01 mg/l	
		- Cast nets	Nitrate - N	352.1	0.01 mg/l	Laboratory analysis will meet or exceed the
		- Water intake screens	Ammonia - N	350.1	0.02 mg/l	requirements set forth in the TWC Quality
			Total phosphorus	365.1	0.01 mg/l	Assurance program (3)
		Tissue - 4 preferred species	Chlorophyll a			
		- Hardhead (sea) catfish	Pheophytin a			Data storage:
		- Pinfish				- side by side data comparisons
		- Atlantic croaker	Total organic carbon (TOC)	415.1	1 mg/l	- computerized parameter value editing
		- Redfish (red drum)	Alkalinity	310.1	1 mg/l	
			Chloride	325.3	1 mg/l	
		Plankton:	Sulfate	375.4		
		- Kemmerer sampler	Total dissolved solids (TDS)	160.1	10 mg/l	
		- Van Dorn sampler	Volatile suspended solids (VSS)	624	10 mg/l	
		- Net hauls	Select stations:			
			Water and Sediment:			
			Organics - pesticides	608/8080	variable	
			Inorganics - alkalinity, hardness major ions			
			Metals	ICP - 6010	variable	
			Toxicity			
			Organisms:			
			nekton - tissue			
			plankton			
			benthos			
Texas Water Development Board (TWDB)	5 Stations	Semi-permanent moored stations using Data Sonde instrumentation	Water: Temperature, salinity, pH conductivity, DO			Instruments are checked and maintained on a regular basis.
(Brock, 1993 and 1994)	supports TCOON					
	8 Stations	Tide monitoring stations within Galveston Bay	Tidal elevation Some meteorological data			NOAA / NOS QA procedures Data inspected daily

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
Texas Parks and Wildlife Department (TPWD)						
1. Resource Monitoring (Bowling and Benefield, 1993) (Robinson, 1994) (TPWD, 1993a)	149 Stations Bay and Offshore Randomly selected from TPWD's grid system The number of usable grids varies for each gear type	Bay Bag Seines: 20 per month Targets juvenile finfish and shellfish 321 usable grids Bay Trawls: 20 per month Targets juvenile and some adult finfish & shellfish 10-minute trawls 369 usable grids GIW (Gulf Intercoastal Waterway) Trawls: 6 per month Targets juvenile and some adult finfish & shellfish 10-minute trawls 77 usable grids Gulf Trawls: 16 per month Targets juvenile and some adult finfish & shellfish 10-minute trawls Oyster Dredges: 30 per month Targets oysters: market, small, and spat 30-second dredge - 126 usable grids Beach Seines: May - November - 6 per month Targets adults in surf zone of front beach Beach Bag Seines: May - November - 6 per month Targets juvenile finfish and shell fish in surf zone Gill nets: 45 nets set during a 10-week period in the spring and fall Targets adult finfish in bay 4 segments of 150' each, 4 mesh sizes - 3" - 6" 1 per segment, shoreline to Gulf 252 usable grids Hook and line: As required by special study	Water: Temperature, salinity, pH turbidity, DO Weather conditions Wind direction Air temperature Organisms: Species Number Weight (select individuals) Length (subsample of 19 ind.) Sex and maturity Large, live fish tagged for growth and mortality			Guidelines follow TPWD Marine Resource Monitoring Operations Manual (4) Gill nets must be set within 1/2 hour of sunset and picked up no earlier than 1/2 hour before sunrise. Work on the last net must start before 11:00 a.m. Field data sheets are edited prior to submission for computer keying Computer printouts of field data are contrasted with field data sheets after computer keying
2. Coastal Resource Harvest Commercial Landings Program (McEachron, Campell, and Robinson, 1993) (Robinson, 1994) (TPWD, 1989)	130 - 140 seafood dealers	Seafood dealer submits reports - pertaining to commercial finfish, shrimp, crabs, oyster, and other marine life Length checks of target species - (200 per species) 5 target species - black drum, flounder, mackerel, red snapper, sheepshead	Organism: Quantity by weight Number of species Price per pound			Guidelines follow TPWD Commercial Harvest Field Operations Manual (5)
	Vessel captains	Commercial bay/bait intercept program was implemented in May 1994 On-site interviews of vessel captains	Trip length Number of drags Total fishing time Minor bay fished Net size Mesh size Amount of live and dead shrimp landed Size of shrimp Species of catch			

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
3. Coastal Resource Harvest Recreational Landings Program (Robinson, Green, and McEachron, 1993) (Robinson, 1994) (TPWD, 1993b)	121 Sample sites 40 additional sites for detecting any change in status Sampling stratified and based on relative fishing pressure at each site. Determined by a computer generated relative pressure system.	On-site trip-end Interviews	Boat registration number Trip length Number of people / residency Minor bay fished Gear: Bait - type and amount Fish landed: Species Total lengths (6 per species) Grade Species sought By-catch - released Trip satisfaction			Interviewers are periodically observed to monitor compliance with operating procedures Guidelines follow TPWD Marine Sport Harvest Operations Manual (6)
City of Houston/Department of Public Utilities (CoH DPU) (Glanton, 1993)	45 Stations in the tidal portions of major bayous		Water: probe Temperature, pH, conductivity Chloride Ammonia - N Nitrate - N BOD TSS FC			
City of Houston/Health and Human Services Department (HHSD) (APHA, 1992) (Fisher, 1993 and 1994) (Krentz, 1993) (U.S. EPA, 1983)	Field Operations : - 54 stream stations - all permitted wastewater dischargers	CoH - HHSD - The Bureau of Public Health Engineering has two groups conducting monitoring Field Operations Unit - Stations are all above tidal waters				Participate in APG proficiency studies twice each year for each analyte listed (chemistry)
			Water: probe Temperature, DO	EPA Methods (1)		Field Notes, information reviewed after computer entry
			BOD	405.1	4 mg/l	Duplicate
			Ammonia-N	350.1	0.05 mg/l	Duplicate, spike, external QC
			Sulfate	300	2 mg/l	Duplicate, spike, external QC
			TDS	160.1	20 mg/l	Duplicate
			TSS	160.2	4 mg/l	Duplicate
			Oil and grease	413.1	1 mg/l	External QC
			Chloride	300	2 mg/l	Duplicate, spike, external QC
			Trace metals:			
			As	206.2	2 mg/l	Duplicate, spike, external QC
			Cd, Cr, Du, Mn, Zn	200.7	10 mg/l	Duplicate, spike, external QC
			Ni	200.7	25 mg/l	Duplicate, spike, external QC
			Se	200.7	1 mg/l	Duplicate, spike, external QC
			Hg	245.2	0.5 mg/l	Duplicate, spike, external QC
			Pb	200.7 / 239.2	40 mg/l	Duplicate, spike, external QC
			FC	Standard Methods (7) 9221 E(1.)	2 / 100 ML	FC bacterial analysis records
	Quality Assurance Group : - Lake Houston and watershed - 6 major Houston bayous	Quality Assurance Group - These bayou stations are all at USGS monitoring stations and include the lowest USGS station at each bayou	Water: probe Temperature, DO	EPA Methods (1)		Field notes, information reviewed after computer entry
			pH	150.1		Buffer check
			TDS	160.1	20 mg/l	Duplicate
			Sulfate	300	2 mg/l	Duplicate, spike, external QC
			Chloride	300	2 mg/l	Duplicate, spike, external QC
			FC	Standard Methods (7) 9221 E(1.)	2 / 100 ML	FC bacterial analysis records

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
Harris County Pollution Control Department (HCPCD)	9 Stations - Houston Ship Channel		Water: probe Temperature, DO, flow	Standard Methods (7) DO = 4500-0 G		Calibrate meter prior to each use
(APHA, 1992) (Barrett, 1993 and 1994) (Tyer, 1994)	6 Stations - on the San Jacinto River		pH	4500-H+		2 buffer standardization and read 3rd buffer prior to each analytical run; restandardize/ reanalyze violations
	Each industrial discharger Municipal dischargers		TOC	5310B	1 mg/l	Standardize prior to each analytical run (optional: check calibration with independent standard), check calibration about every 10 samples and at end of run. Reanalyze violations, including spike analysis
			Trace metals: As Cd Cr, Ni Cu, Mn Zn	 3111/3113 3111 3111 3111 3111	 0.001 mg/l 0.002 mg/l 0.02 mg/l 0.01 mg/l 0.005 mg/l	Two point calibration prior to each analytical run; check calibration about every 10 samples. One replicate analyzed with each run. Reanalyze violations, including spike analysis.
			Total solids (residue)	2540B		Control dish (no sample)
			TSS	2540D		One random replicate with each analytical run and/or replicates on any suspected violations; reanalyze any violation without previous replicate; water blank and control crucible (no sample) with each run
			Ammonia - N	4500	0.03 mg/l	Standardize prior to each analytical run; one random replicate analyzed with each run; check calibration with two different standards (concentrations) one during run and other at end of run
			FC/Fecal Streptococcus (FS)	Modified 9222D/9230C	10 / 100 ML	Periodically analyze replicates, system blank, air density plate and known active sewage
			Volatile acids (VA)	Qualitative		Periodically analyze known cyanide solutions
			Sulfide	Qualitative		Periodically analyze known sulfide solutions
			Chloride	Harris County Method	7 mg/l	Periodically analyze chloride standard
Galveston County Health District Pollution Control Division (GCHD) (APHA, 1989) (Fogerty, 1993 and 1994) (Wright, 1994)	120 Stations including Galveston Island - beach, bayside, ship channel, and bayous Mainland county bayous, creeks, some drainage ditches Texas City Ship Channel and Dike	Collect water quality samples only Grab samples usually, composites rarely Samples collected on monthly, bi-monthly, and tri-annual basis	Date and time Wind direction Wind speed Cloud cover Rainfall Days prior rainfall and amount Tide (high/low) Flow direction (in/out) Sample depth Air temperature Water temperature	Use NOAA weather information for: wind direction, speed, and rainfall Use daily rainfall data from wastewater treatment plants throughout county		Field meters are calibrated using manufacturers guidelines before each use. Manufacturer services meters as necessary. Laboratory uses standard QC methods (blanks, spikes, controls and duplicates) EPA required controls implemented for those tests performed for contracted services for cities

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
	Permitted dischargers Complaint sampling		DO, salinity, conductivity pH Water color Observed turbidity or Secchi disc BOD TSS FC Occasionally: Chemical oxygen demand (COD) Ammonia-N Total phosphorus Oil and grease Extra capabilities: TDS Volatile suspended solids (VSS) orthophosphate	YSI field meters Corning or Orion meters 4500-H Standard methods Standard Methods (8) 5210 B 2540-D 5220 B 4500 NH3 B 4500-P-B-5 5520 B 2540-C 2540-E 4500-P-B	2 mg/l 0.01 mg/l 0.02 mg/l 0.01 mg/l	
Chambers County Environmental Health Department (Jackson, 1994)	Trinity Bay - respond to septic/ sewage complaints Lake Anuhuac	No monitoring programs in Galveston Bay	FC			
U.S. Environmental Protection Agency (EPA) Environmental Monitoring and Assessment Program (EMAP) (Heitmuller and Valente, 1991) (Hornig, 1993) (Summers et al., 1992) (U.S. EPA, 1983 and 1991)	5 Stations in the vicinity of 5 marinas 6 Stations in East Bay Bayou	Water quality - two models of dataloggers - Surveyor II - instantaneous measurements - Data Sonde 3 - continuous measurements Water clarity - LICOR L1-1000 containing a submersible light sensor Light penetration - Secchi disk Fish: Trawling with a 16', high rise otter trawl with a 2.5 cm mesh cod end - towed for 10 minutes against tide Target species for tissue contaminants: - shrimp (brown and white) - Atlantic croaker - catfish (hardhead, gafftopsail, and blue) Composite of 4 - 10 individuals per site Bivalves: Modified oyster dredge with collection bag towed over the bottom - 5 minutes at approximately 1 m/s	Water: probe Temperature, salinity, pH, DO Water clarity Water depth Light Marine debris Fish: Number of species Total abundance Gross pathology Bivalves: Total abundance Species composition Shell length Fish and bivalve tissue: Pesticides, PCBs Heavy metals Benthic community parameters Grain-size analyses			Crew training and sample collection: - chief training - crew training - field certification / auditing - testing and scoring of personnel Water quality measurements: Field quality control checks - instantaneous and continuous measurements - All datalogging units are calibrated with documentation within the 24-hour period preceding their scheduled use - side by side measurements between Data sonde and Surveyer (standard) - QC data compiled and evaluated to determine the frequency of acceptable and unacceptable adherence to QA guidelines Laboratory certification and chemical analyses: - laboratories must pass a certification prior to analyzing any samples - usual QC methods (blanks, spikes, controls, and duplicates) - standard reference materials (SRMs) with certified values for metals and organics

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
		Benthos: Young - modified Van Veen grab which samples a surface area of 440 square cm - 3 grabs at base, index, or supplement sites - 5 grabs at indicator sites Grain-size analyses: Small core (60 cc) from each grab - sieved	Sediment: Toxicity Ampelisca abdita Mysidopsis bahia Alkanes and isoprenoids PAHs Pesticides, PCBs Heavy Metals: Ag, Al, Cr, Cu, Fe, Mn, Ni, Pb, An As, Cd, Sb, Se, Sn Hg Butyltins TOC	 10-day acute bioassay 4-day acute bioassay GC/MS GC/ECD ICP-AES ICP-AES GFAA CVAA		Laboratory testing and analyses: - scheduled recounts and resorts for benthic assessments - experimental controls for sediment toxicity testing - scheduled replication for sediment characterization - use of blank, spikes, and standards for chemical assessments - EMAP-E personnel visit each of the laboratories at least once while EMAP-E analyses is occurring
R-EMAP-TX program	33 Stations - 29 systematic grid sites - 4 randomly selected bay sites		Sediment: Detailed chemistry Benthic communities			
U.S. Geological Survey (USGS) (Fisher, 1994) (Liscom, 1993)	2 stage gages 4 automatic monitoring stations 12 stations	USGS - stage gage - Moses Lake - stage gage - Hwy 90 at San Jacinto River Freshwater inflow monitoring	stage and precipitation stage Water: probe Temperature, salinity, pH conductivity Surface water elevation Surface water elevation - hourly Freshwater inflow - hourly 4 to 6 samples per year BOD COD FC FS TOC Nutrients Selected pesticides/herbicides Specific conductance Water temperature			Instruments are checked, maintained, and calibrated on a regular basis
Galveston Bay Foundation (GBF)	Approximately 34 stations in tidal segments	Grab samples are taken 1 foot below surface Samples are collected weekly or bi-monthly	Water: temperature, DO, pH, salinity, conductivity, turbidity Weather: wind direction, intensity, days since last rainfall air temp. Other: total depth, water level, odor, site observations, tide, color	Standard Methods: 2550-B 4500-o C 4500-HB 2510 B		GBF follows the Texas Watch QAPjP Monitors receive Texas Watch (TNRCC) training Monitors participate in 2 QC sessions per year Conductivity pens are calibrated prior to each monitoring event DO chemicals are changed every 6 months

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
U.S. Fish and Wildlife Service (USFWS)	Entire estuary - every 10 years	USFWS - National Wetlands Inventory - program of mapping wetlands using aerial photography	Vegetation groups:	Photo analysis Ground truthing		
(Special Study) Galveston Bay National Estuary Program (GBNEP) (Carr, 1993) (Jensen et al., 1993)	24 Stations 16 stations selected in depositional zones away from known point source discharges 8 stations selected based on specific areas of concern A GPS navigation receiver was used determine station locations	Sediment: - collected with a 4" diameter coring device Benthos: - collected with a 2" diameter coring device	Water: probe Temperature, salinity			NS&T QA/QC Procedures
			Water depth			
			Sediment: Trace metals: Al, Br, Be, Cr, Cu, Fe,	DCP		
			Mg, Mn, Ni, Tr, Vd, Zn	DCP		
			As, Cd, Pb, Se	GFAA		
			Hg	CVAA		
			PAHs	MS in the SIM mode		
			Pesticides, PCBs	CGC		
			TOC	Coulometer TOC analyzer		
			AVS	GFAA		
			Toxicity: *Grandidieralla japonica*	10-day solid-phase bioassay		
			Pore water: DO, pH, hydrogen sulfide Temperature, ammonia			
			Toxicity: gametes Arbacia punctulata	Fertilization test Morphological development assay		
			Benthic community parameters Total abundance Species composition Species diversity Species richness			
National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program (NSTP) (Presley and O'Conner, 1993)		(continued on following page)				NS&T Program Methodology - performance based Analysis of reference materials and control materials is required

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
1. National Benthic Surveillance Project (NBSP) (NOAA, 1993)	9 Stations : a nominal site center has been defined for NBSP sites as an area 2 km in diameter and is revisited for sample collection	Sediments were collected concurrently with fish specimens at each NBSP site Sediment: - specially constructed box corer - standard Smith-MacIntyre bottom grab the water was drained before sediment was taken Fish: - primarily collected by otter trawls towed by NOAA vessels - occasionally by hook and line or gill nets	Sediments: Organic compounds: Pesticides, PCBs PAHs Coprostanol	 GC/ECD GC/FID/MS GC/FID	 0.0001 ug/g 0.0010 ug/g	Trace organic analytical procedures - internal standards are added at the start and carried through analyses Calibration checks - plus or minus 10% of the accuracy based value for standards All samples must be quantified within the calibration range Method Detection Limits (MDLs) are calculated and reported annually - Since 1989, method for calculating MDLs is that used by the EPA If EPA method is not used - the procedure is described in detail Precision - defined limits Accuracy - defined limits A minimum of 8% of an analytical sample string should consist of blanks, reference or control materials, duplicates, and spike matrix samples Data acceptability criteria reported annually Intercomparison exercises Quality assurance workshops Development of standard reference and control materials
			Major and trace elements: Si, Al, Fe Cr, Zn, Mn Ag, As, Cd, Cu, Ni, Pb Hg	 FAA FAA, GFAA GFAA, FAA, HAA CVAA	 Ag, Cd, Hg = 0.005 ug/g Cr, Pb = 0.2 ug/g As, Cu = 0.05 ug/g	
			Clostridium perfringens TOC Moisture content Particle size	plate count CHN analyzer drying at 120 degrees C Wet sieving techniques		
			Fish Tissue: Organic compounds: Pesticides, PCBs PAHs - stomach contents PAH metabolites - bile	 GC/ECD GC/FID/MS HPLC/FID	 0.001 ug/g 0.01 ug/g 0.01 ug/g	
			Major and Trace elements: Al, Ag, As, Cd, Cr, Ni, Pb, Sb, Se, Sn, Tl Fe, Mn, Cu, Zn Hg	 GFAA GFAA FAA CVAA	Ag, Cd, Hg = 0.001 ug/g Cr, Pb = 0.04 ug/g As, Cu = 0.01 ug/g	
			Tissue dry weight Otoliths or scales - fish age	Oven drying		
2. Mussel Watch Program (MWP) (NOAA, 1993)	6 Stations: Sites were defined using Global Positioning System Technology	When taken, sediment samples were collected concurrently with bivalve samples Sediments: - stainless steel box core - Teflon-coated sampling scoop Oysters: American oyster - hand (preferred), tongs, or dredge	Water: probe Temperature, salinity, depth			National Institute of Standards and Technology (NIST) trace organic exercises - performance based National Research Council (NRC) trace element exercises - performance based
			Sediments: Organic compounds: Pesticides, PCBs PAHs Coprostanol	 GC/ECD GC/MS GC/FID	 0.0001 ug/g 0.0010 ug/g	
			Major and trace elements: Al, Cr, Mn, Fe Ni, As, Se, Ag, Cd, Sn, Pb Cu Zn Hg	 NAA GFAA GFAA, FAA FAA CVAA	Ag, Cd, Hg = 0.005 ug/g Cr, Pb = 0.2 ug/g As, Cu = 0.05 ug/g	
			Clostridium perfringens TOC Moisture content Particle size	plate count carbon analyzer 24 hours at 45 degrees C Dry sieved		
			Oyster tissue: Organic compounds: Pesticides, PCBs PAHs	 GC/ECD GC/MS	 0.001 ug/g 0.01 ug/g	

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
			Major and trace elements: Al, Mn, Fe, Zn Cu Cr, Ni, As, Se, Ag, Cd, Sn, Pb Hg Tissue dry weight Shell size Radionuclide samples - 1991 Gonadal index	 FAA FAA/GFAA GFAA CVAA Oven drying	Ag, Cd, Hg = 0.001 ug/g Cr, Pb = 0.04 ug/g As, Cu = 0.01 ug/g	
National Marine and Fishery Service (NMFS) (Zimmerman, 1993) 1. Baseline Production 2. Brown Shrimp Catch Program 3. Post Larval Shrimp Program (discontinued in 1993)	 Variable stations in West Bay marsh 6 Stations	 Fish, shrimp, and crabs are sampled using drop samplers NMFS - brown shrimp - Interviews with bait dealers and fishermen - Reviews of fishermen's logs Samples are collected with a 5' long, small-meshed, modified hand-held beam trawl	 Organisms: Densities of target species Biomass Catch per unit effort Pounds per hour Water: probe Temperature, salinity Tide condition Catch per 100 square meters of bottom area Length (size of shrimp)			
Texas Department of Health (TDH) (APHA, 1970) (Wiles, 1993)	104 Stations - approved shellfish harvest areas - conditionally approved waters	Water samples are collected 2 feet under the water surface while other parameters are measured by probes.	Water: probe Temperature, DO, salinity Weather conditions: Air temperature Raintall Wind direction Wind velocity Tide conditions FC			National Shellfish Sanitation Program NSSP QA/QC Guidelines (9)

TABLE 1.1. REGIONAL MONITORING ACTIVITIES IN GALVESTON BAY ESTUARY (continued)

AGENCY/ORGANIZATION (Source)	No. OF STATIONS	DATA COLLECTION ACTIVITIES	PARAMETERS MONITORED	ANALYTICAL METHODS**	DETECTION LIMITS	QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)
U.S. Army Corps of Engineers (USCE) 1. Dredged Material Monitoring Program Galveston District (Medina, Hauch, and Arhelger, 1993) (U.S. EPA, 1986 and 1991)	6 core stations in the Houston Ship Channel	Samples collected by a bottom grab	Heavy Metals As Cd Cr Cu Ni Pb Zn Se Hg Oil and grease PCBs PAHs Pesticides Grain-size analyses Toxicity Bioaccumulation	EPA methods (2) 7060 7131 7191 7211 7521 7421 7951 7740 7470 10-day solid phase bioassay 28-day bioaccumulation		Dredged Material Testing Manual QA/QC Guidelines (10) - 10% of laboratory samples are field duplicates - One sample of every 10 - 20 samples are analyzed in triplicate
2. Open Bay Disposal Dredged Material Program - Waterways Experiment Station (3 year program scheduled to finish in 1994) (Clark and Ray, 1993) (U.S. EPA, 1986 and 1991)	30 Stations: Open Bay	Samples collected with a box corer Sediment profiler	Sediment: Sediment profile imagery Grain-size analyses Sediment carbon Redox potential Surface relief Benthos parameters	EPA methods (2)		Dredged Material Testing Manual QA/QC Guidelines (10)

NOTES:

(1) U.S. EPA. 1983. Methods for chemical analyses of water and wastes, 2nd Edition. EPA 600/4-79-020. U.S. Environmental Protection Agency, Environmental Support Laboratory.
(2) U.S. EPA. 1986. Test Methods for Evaluating Solid Wastes, 3rd Edition. EPA SW-846. U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, Washington, D.C.
(3) TNRCC. 1993. Quality Assurance Project Plan for Environmental Monitoring and Measurement Activities, Surface Water Monitoring. Texas Natural Resource Conservation Commission, September 1993.
(4) TPWD. 1993a. Marine Resource Monitoring Operations Manual. Texas Parks and Wildlife Department, January 1993.
(5) TPWD. 1989. Commercial Harvest Field Operations Manual. Texas Parks and Wildlife Department, January 1989.
(6) TPWD. 1993b. Marine Sport Harvest Monitoring Operations Manual. Texas Parks and Wildlife Department, July 1993.
(7) APHA. 1992. Standard Methods for the Examination of Water and Wastewater, 18th Edition. American Public Health Association, Washington, D.C.
(8) APHA. 1989. Standard Methods for the Examination of Water and Wastewater, 17th Edition. American Public Health Association, Washington, D.C.
(9) APHA. 1970. Recommended Procedures for the Examination of Seawater and Shellfish. American Public Health Association, Washington, D.C.
(10) U.S. EPA. 1991. The Near Coastal Laboratory Procedures Manual. Environmental Monitoring and Assessment Program. U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory, Cincinnati, OH.

**** ABBREVIATIONS:**

AES - Atomic emission spectrometry
CGC - Capillary gas chromatography
CHN analyzer - Carbon-hydrogen-nitrogen analyzer
CVAA - Cold vapor atomic absorption
DCP - Direct coupled plasma
ECD - Electron capture detection
FAA - Flame atomic absorption
FID - Flame ionization detector
GC - Gas chromatography
GC - Gas chromatography
GFAA - Graphite furnace atomic absorption
HAA - Hydride generation atomic absorption
HPLC - High performance liquid chromatography
ICP - Inductively coupled plasma
MS - Mass spectrometry
NAA - Neutron activation analysis
SIM - Selected ion monitoring

established methods; sampling and analytical equipment are already available, data analysis procedures are established, and field and analytical staff do not require additional training.

Appropriate analytical sensitivity of routine monitoring methods has been cited as an essential criterion for agencies in the performance of their mandated responsibilities. Accuracy and precision of analytical methods are also important criteria so closely linked to sensitivity that the three criteria must be considered together. Sampling or analytical methods must be sufficiently sensitive and precise, and the data sufficiently accurate to detect both seasonal variability and long-term trends in the monitored parameters.

The robustness or adaptability of a monitoring method is an essential characteristic when considering a long-term regional monitoring effort. A sampling method that cannot be employed with consistent results throughout the monitored region or under the normal range of environmental conditions cannot be used effectively in a regional program. The same is true for analytical methods that may be subject to degradation of sensitivity, accuracy, or precision from chemical or biological interference mechanisms that may be encountered.

1.3 DOCUMENT LAYOUT

The Regional Monitoring Protocols are composed of several major monitoring components identified by the GBNEP program office and described in the Comprehensive Conservation and Management Plan (CCMP). One extra topic has been added to these six components. This addresses the recommended protocols for sample station positioning, i.e., how the latitude and longitude of each sampling event are determined. This topic is discussed before all the others because it applies directly ands equally to all field sampling efforts undertaken for the Regional Monitoring Program, regardless of whether sample collection or monitoring observations are conducted from a vessel, on land, or from the air. The monitoring protocols are organized into these components:

- Station positioning
- Water quality (which includes the topic Hydrodynamics)
- Sediment quality
- Habitat protection
- Species population protection
- Public health protection.

The specific Resource Management Objectives that are directly or indirectly related to each major monitoring component and that can be supported by environmental monitoring efforts are identified at the beginning of the description for each recommended monitoring activity.

Table 1-2. SELECTION CRITERIA FOR MONITORING PROTOCOLS

- **Comparability**—the measure of whether data collected by the method is directly comparable to existing data for the same parameter

- **Cost**—the combination of implementation, equipment maintenance, and per sample costs

- **Sensitivity**—the measure of the ability to detect target parameters at low levels, sufficient to distinguish between seasonal variability and long-term trends.
- Accuracy—the measure of the agreement between the amount of a component measured and the amount actually present

- **Precision**—the measurement of the reproducibility of results when a method is repeated using a homogeneous sample under controlled conditions, regardless of systematic or constant errors that may affect the accuracy of the method.

- **Robustness**—the measure of method adaptability to the range of seasonal environmental conditions experienced across the estuary and to the range of expected target contaminant concentrations and non-target interference matrices and mechanisms.

The Protocols described in this document address only sample collection and sample analysis efforts designed to measure ambient conditions. The document is not intended to discuss monitoring strategies, such as sampling frequency, sample collection locations within the bay, sampling density throughout the bay, sampling segmentation regimes, or the delineation of "hot-spots." These monitoring strategy issues are discussed in the *Galveston Bay Regional Monitoring Strategy* (Tetra Tech, 1994) and the draft *Galveston Bay Regional Monitoring Program* (GBNEP, 1994).

A chapter is devoted to each of the six major components. Where appropriate, each chapter is divided into sections, each devoted to a single parameter for which a monitoring protocol is recommended. Specific parameters and/or indicator species, proposed by the Monitoring Steering Committee participants, are listed. The discussion of each monitoring protocol is further divided into the following sections and descriptions, when appropriate:

- **Data use and limitations**
  - Discusses the Resource Management/CCMP Objectives that are directly supported by this specific monitoring effort
  - Discusses those Resource Management/CCMP Objectives that are partially supported by this specific monitoring effort
  - Discusses Agency mandates or objectives for which this monitoring effort is performed

- Describes information provided by the monitoring effort including a description of how the data is used.

- **Sampling and analytical methods**
  - Identifies methods used for existing monitoring programs and special studies
  - Recommends and outlines a preferred method and equipment for sample collection
  - Recommends a preferred method and equipment for sample analysis.
  - Includes full citations and references for all published protocols, and agency contacts for unpublished protocols
  - May include a description of ancillary data to be collected
  - May include a description of an available alternate monitoring method

- **QA/QC considerations**
  - Describes QA/QC conducted under existing programs for sample collection and handling
  - Describes QA/QC conducted under existing program for sample analysis
  - Recommends changes/additions to QA/QC as required to meet needs of the Regional Ambient Monitoring Program.

All recommended sampling and analysis protocols are derived from existing methods used by the various agencies with resource monitoring and protection responsibilities within the Galveston Bay estuary. Thus, descriptions of methods are either referenced by citing the appropriate procedures manuals, or summarized directly from existing agency operations/protocol manuals when such documents are not widely available. Other methods, not formally committed in writing (or at least, not identified in a written format, are described in more detail. In the case of suggested alternate methods, descriptions of protocols have been based on methods used in special studies conducted within Galveston Bay or methods used in other estuarine studies or monitoring programs.

Because of the diverse sources of information and the wide range of environmental parameters addressed in these monitoring protocols, the level of descriptive detail varies between different sections of the document. However, in all cases, all existing documented methods and all sources contacted (personal communications) are cited and fully referenced. It is hoped that this information will be sufficient to assist the reader in gathering further information on any of the monitoring methods for which he has an interest.

This draft document can be considered a basic staging point for the Regional Monitoring Program. The selection of methods has been accomplished with guidance from the five Monitoring Steering Committee focus groups. The information presented is expected to evolve in both content and level of detail in response to continued review by and suggestions from Committee members. The final version of this document will be published in a loose-leaf format. This will facilitate revisions and updates to specific collection and analytical methods as new techniques and variations in monitoring strategies are developed.

CHAPTER 2
STATION POSITIONING

This section addresses the process of positioning a sampling vessel on a station during field sampling. The process of locating the sample collection point from a boat has traditionally involved use of a fixed marker of some type. These are generally navigation aids or oil platforms or, in the case of a narrow channel, a shore marking. One consequence of this positioning procedure is that, to some degree, stations tended to be confined to more heavily used areas, and open bay locations tended to be under-represented in the sampling.

With the advent of relatively inexpensive LORAN and Global Positioning Systems (GPS) electronic navigation systems, which are capable of quite high accuracy if necessary, there is no longer any field need to be restricted to fixed marks. It is useful, however, in the human communication process to be able to refer to commonly known locations. The ability to select a location (latitude/longitude) without having to be near a fixed mark should make the station positioning process more flexible.

2.1 DATA USE AND LIMITATIONS

The primary functions of station positioning are to properly locate the sample collection point in the field and to properly record the sample collection point in the data record. While traditional monitoring efforts have found it convenient to merely identify a station by a name, with geographic coordinates stored separately, the advent of Geographic Information Systems (GIS) and ease of spatial plotting makes it desirable to have coordinates stored directly with the station data.

Having the information on position in a form suitable for direct plotting raises the need to consider the type of use and the need to have data storage consistent with positional accuracy. For example, generally no great positional accuracy (e.g., +/- 500 m) is necessary for sampling in an open bay to characterize ambient water or sediment conditions for routine purposes. On the other hand, it is possible that monitoring that has a legal or enforcement purpose may have very different positioning needs. For this discussion, it is assumed that all monitoring for the Galveston Bay Program will be limited to non-legal purposes.

With the advent of smaller and cheaper positioning systems, monitoring crews can improve sample positioning with little additional effort. A single, stand-alone GPS unit is capable of a precision of better than ±100 meters when receiving the standard Coarse/Acquisition (C/A) code.

2.2 RECOMMENDED METHODS

All sampling crews should be equipped with a portable GPS receiver that has both a visual display and provision for digital transfer of coordinates to any of a number of data logging systems or a portable computer. The position should be recorded digitally as well as on paper from the visual display at the approximate midpoint of data collection at a station. If the nature of the data collection is to extend over a longer time or distance (e.g., a trawl), the position should be recorded at the beginning of the activity, at fixed intervals during the activity and at the end of the activity.

USEPA has published a reference that provides an overview of GPS survey methods and procedures, from initial planning to data reduction and postprocessing:

> *GIS Technical Memorandum 3: Global Positioning Systems Technology and Its Application in Environmental Programs.* EPA/600/R-92/036. EMSL, Las Vegas. U.S. Environmental Protection Agency, 1992.

2.3 QA/QC CONSIDERATIONS

As with any mechanical or electronic system, it is important that the human operators monitor performance and maintain a check on accuracy. In the case of an electronic latitude-longitude readout, the vessel operator should always monitor the position of the vessel relative to visual landmarks and aids to navigation, and check to see that the electronic readout is approximately correct. In addition, it is important to perform accuracy checks with each sampling trip. These would consist of checking the latitude-longitude of a known position at the beginning and end of each sampling trip. If there is a significant departure of the known position, the difference must be recorded and measures taken to correct the position data collected during the trip.

2.4 ALTERNATIVE METHODS

Improved positioning can be obtained by using differential techniques. These methods require a second receiver to be recording at a known reference point to compensate for the errors inherent in the satellite positioning data. Error correcting messages can be sent in real-time via a radio link between the two GPS units to continuously update the mobile unit. Another alternative is to record the corrections and apply them after the survey is completed. In this case the radio link between the reference and mobile GPS units would not be necessary. The potential accuracy for these differential methods can range between 1.0 - 10.0 meters, with 3 - 4 meters being the usual range (EPA, 1992). U.S. Coast Guard plans for establishing a network of differential GPS reference stations around the coast may provide a third and more convenient alternative to differential GPS usage.

In addition to the advantage of flexibility in site selection, using GPS offers an improvement in the data logging and transfer process. Currently, it is generally necessary to enter the station location first on paper in the field log and then to an electronic media via keyboard, along with the various parameter values. Keyboard data entry entails additional labor costs and a certain percentage of entry errors which are inherent in the process. With much of the data being generated from instruments in the field, inclusion of position information directly in the automatic data logging process would increase both monitoring efficiency and reliability.

Obviously alternatives are available. LORAN-C can provide digital information at a slightly lower cost but with a substantial drop in accuracy ($\pm$ 500 m). However, because of the trend of monitoring agencies requiring more stringent accuracy, it is recommended that an integrated GPS/data recording system be the first choice for sampling positioning.

CHAPTER 3
WATER QUALITY

This section addresses water quality considerations. Specific topics included under this broad heading include:

Hydrodynamics or water movement
Water column sampling procedures
Chemical analyses.

The chemical analyses section is further subdivided into the broad and sometimes overlapping groupings of conventionals, nutrients and toxics.

This section generally supports all of the Water and Sediment Quality Goals of the Galveston Bay Program. It should be noted that monitoring tends to lend itself to assessment of goals and objectives rather than specific plan actions.

3.1 HYDRODYNAMICS

The term hydrodynamics means, literally, the movement of water. In this context it refers to tides and currents, as affected by both wind, freshwater inflows and lunar/solar gravitational fluctuations (astronomical tides). One of the purposes of having hydrodynamic data is to facilitate the interpretation of water quality data. For example, if the TSS concentrations on a given day were higher than typically observed at a station, it may be because the wind was unusually high, resulting in larger than normal waves which re-suspended bottom sediments, or it may be because of some other reason such as recent rains and high freshwater inflows or a phytoplankton bloom. Resolving this point could be quite important in determining if a trend could be detected. A similar statement could be made for nutrient or salinity concentrations, which could be strongly influenced by the state of the tide.

3.1.1 Data Use and Limitations

Monitoring data on the hydrodynamics within the bay can provide information to be used in support of the assessment of the following Resource Management Objective:

FW-4: Complete an evaluation of bay circulation patterns and their effects on bay habitats and species by 1999.

The present monitoring procedures in Galveston Bay provide for very specialized approaches to hydrodynamic data collection, but little or no activity in this regard is performed in the routine programs of the TNRCC and local agencies. For example, there is a tide gage network active along the Texas coast with eight stations located in Galveston Bay (the Texas Coastal Ocean Observation Network, TCOON, operated by the Conrad Blucher Institute in conjunction with the TWDB), as well as tide gages operated by the National Ocean Survey (NOS) and the Corps of Engineers (COE). However, no procedures are in place for recording the tide level when a sample is collected. There is no ongoing program to record currents in the bay, although the COE and other agencies, including NOAA-NOS, have performed short-term current monitoring studies over the last several years.

The TWDB operates five permanent continuously recording stations for water quality data collection to support their modeling programs for circulation and salinity. Freshwater inflow gaging stations are largely supported by the U.S. Geological Survey (USGS) and some local entities such as cities and river authorities. Rain gages and wind data collection are supported by the National Weather Service as well as airport authorities and cities. All of these sources together provide sufficient data to estimate the currents in the bay, with an accuracy which is sufficient for all routine purposes. While none of these data sources exist to support the Galveston Bay Program management goals, they all provide essential support to the full range of goals and objectives.

3.1.2 Sampling and Analytical Methods

As the primary need for hydrodynamic information is to aid in the interpretation of other water quality data, and because there is already an established data collection network in place, the approach recommended is to incorporate this network into the overall Galveston Bay Regional Monitoring Program (GBRMP) by reference. Assessing currents will not be considered as a monitoring element for the GBRMP. The principal benefit that the GBP can provide is to facilitate the linking of the various data sources which would allow ready use of the data in support of GBP goals.

Alternative Methods

In theory it would be possible for the agencies with a water quality responsibility to begin their own collection programs for hydrodynamic data. While this is possible, it is not recommended as it would be duplicative and wasteful. However, the need for surveys to assess specific problems associated with bay circulation, especially those involving in-bay construction or shoreline alterations, either man-made or natural may arise. It is recommended that a study plan be devised to establish baseline conditions and post-construction altered flow patterns in the case of planned construction or alteration, once the location and extent of the planned project is known.

3.1.3 QA/QC Considerations

All of the agencies involved in hydrodynamic data collection have their own programs in this area. Because no effort is recommended to modify the agency data collection programs, existing agency QA/QC procedures are recommended. In the case of the need for a special study, as discussed above, QA/QC procedures pertinent to the proposed study (i.e., types of measurements, types of instrumentation) would need to be specified as part of the study plan.

3.2 WATER COLUMN SAMPLING

Monitoring water quality in the Galveston Bay estuary will provide data necessary to directly assess or support attainment of the following Resource Management Objectives:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014

WSQ-2: By 2004, ensure that all water quality segments within the estuary are in compliance with established dissolve oxygen criteria

Almost all monitoring involves locating a probe in the water column or the collection of samples at various depths for analysis. This section addresses the process of selecting the point(s) in the water column to sample and the methods of collecting the samples.

3.2.1 Data Use and Limitations

The *Texas Surface Water Quality Standards* (Section 307.9) specify sampling procedures for determining standards attainment. For bacterial and temperature comparisons, water column sampling involved collecting the sample one foot below the surface in all cases. However, for other *Standards* parameters (e.g. DO, pH, TDS) the collection depth varies depending on the type of water body. For well-mixed non-tidal streams, the one foot depth is sufficient. For vertically stratified non-tidal streams, bays and tidal streams a surface to bottom depth-integrated sample is specified. However, for bays the definition is the "natural" bottom, excluding dredged areas. In the case of tidal streams, if density stratification occurs, only the data in the "mixed surface layer" are to be used to determine standards attainment. Aquatic toxicity criteria apply to any single sample while human health criteria apply to the vertical average of water column samples.

3.2.2 Sampling and Analytical Methods

There are two basic types of sampling to be addressed. One is where a single sample can be used to represent the water column and the other is where multiple observations must be taken to obtain a vertical profile. The first is used when the water column is vertically homogeneous and the second when there are vertical differences. A second issue is the intervals to be employed when doing a vertical profile of the water column.

There are two techniques for collecting a depth-integrated sample. One is compositing discrete samples collected at various depths. The other is the depth-integrated sample collected via a continuously running submersible pump. The pump is lowered to the bottom and raised at a constant rate, with the discharge collected in a clean container. The water in the collection container becomes a depth-integrated sample, which can be subsampled.

These two techniques are virtually equivalent when used to monitor shallow estuaries, differing primarily in the amount of time and type of equipment required. For example, the submersible pump attached to the probe assembly can readily be used to generate a depth-integrated sample by careful control of the lowering and raising procedures. Water bottle samplers generally consist of a cylindrical tube with stoppers at each end and a closing device that is activated from the surface by a messenger or an electrical signal. The most commonly used samplers of this kind are the Kemmerer, Van Dorn, and Niskin samplers. These devices collect a discrete sample of water at any designated depth.

Recommended Methods

The Galveston Bay Program recommends procedures follow the *Texas Surface Water Quality Standards*, dated July 10, 1991. The Standards, as well as describing sampling depths for different water bodies (non-tidal streams, impoundments, bays, and tidal streams), also reference collection and preservation procedures set forth in the most recently published *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992).

The use of pumped water systems for either discrete or continuous water sampling is the most common method and is recommended for all but trace metal samples. All tubing should be thoroughly flushed through with the sample water before a sample is taken for analysis. Especially in relatively shallow estuarine areas, such pumped water systems are very convenient to use and are less expensive than a set of discrete water samplers.

A dedicated and specially cleaned peristaltic pump with in-line disposable filters can be used for metal samples. This method is recommended in the TWC (now TNRCC) manual:

> *Water Quality Monitoring Procedures Manual Draft*, June 1993. Water Quality Monitoring Team, Texas Water Commission (TWC, 1993).

However, due to the relative ease with which trace metal sample contamination can occur, discrete water samplers are highly recommended for these samples and are essential for any ultra-clean procedures. The recommendation for discrete sampling is simply that the pump system proposed for all other parameters, a high volume-low head pump (e.g., bilge pump), does not meet the ultra-clean requirements for metals sampling. A peristaltic pump, with suitably clean tubing and separation from other potential sources of contamination, could be employed for this purpose.

The most suitable containers for the collection, processing, and storage of trace metal samples are made of quartz or fluoropolymers such as polytetrafluoroethylene (PTFE) and tetrafluoroethylene (TFE). Care should be exercised to avoid contamination of the sampler as it passes through the surface layer during deployment and retrieval. The sampling vessel should be positioned so that the sample bottle can be deployed outside the possible influence of the vessel. As with all parameters, once the water sampler is brought on board the sampling vessel, the stoppers should be checked to see if any leakage has occurred. If a stopper is not properly sealed, water from the sampled depth may have leaked out during retrieval and been replaced by water from shallower depths. In such cases, the entire water sample should be rejected.

When collecting a depth-integrated sample, a continuous profile is, in theory, the most representative. However, for probe measurements it is not practical to record data continuously. Three-meter (10-ft) intervals are currently used by the TNRCC in navigation channels and would continue to serve as an adequate basis of information. Measurements at a finer resolution are easily obtained through the use of automated probes and data loggers, but do not seem practical when considering the cost of additional samples and data storage.

Alternative Methods

The use of discrete samplers or pumps can be determined by the sampling purpose, given that sample contamination concerns are adequately addressed in all cases. Other satisfactory sampling methods that have been used in Galveston Bay include a pressure driven sewage sampler and submerging a sample container by hand to obtain near-surface samples. Again it is important that quality and contamination concerns are properly addressed.

3.2.3 QA/QC Considerations

Since some types of sample results can be greatly affected by sample contamination, appropriate precautions should be taken to avoid contamination at every stage of sample collection, handling, storage, preparation, and analysis. Prior to use, sampling and laboratory equipment must be cleaned as needed for the particular sample type. For example, water sampling bottles that are used to collect samples for measurement of ambient metal concentrations must not contain metal or rubber parts that may contaminate the water sample.

In the field, sources of contaminants could include sampling gear, lubricants and oils, engine exhaust, airborne dust, tobacco smoke, and ice used for cooling samples. During sample handling, preparation, and analysis, samples may become contaminated from exposure to airborne dust, insufficiently clean sample containers, contact with inappropriate materials, contaminated reagents, and carry-over in testing instruments due to insufficient cleaning or flushing between samples. Field personnel can also contribute directly to sample contamination. Field and trip blanks should be run to detect any outside sample contamination.

The *Texas Surface Water Quality Standards* refer to the *Standard Methods* (APHA, 1992) for QA/QC procedures for sample collection and preservation. The TWC (now TNRCC) draft *Water Quality Monitoring Procedures Manual* (TWC, 1993) also provides specific QA/QC procedures for water sampling.

3.3 CONVENTIONAL PARAMETERS

The term "conventional" in a water quality context has evolved over the last decades to distinguish between more specialized types of parameters, but has itself no clearly defined meaning. For this methods manual, it will be considered to include the following water column parameters:

Dissolved Oxygen (DO, probe)
Oxygen Demand: BOD5 and CBOD5; COD
Total Organic Carbon (TOC)
Salinity or Total Dissolved Solids (conductivity, probe)
Hardness (if salinity < 2ppt)
Chlorides and Sulfates (if salinity < 2ppt)
pH (probe)
Temperature (degrees C)
Total Suspended Solids (TSS)
Volatile Suspended Solids (VSS)
Fecal Coliform (FC) bacteria

Most of these parameters are routinely monitored by the TNRCC, as well as federal, City of Houston, and County agencies.

3.3.1 Data Use and Limitations

The Resource Management Objective addressed directly by monitoring conventional water quality parameters is:

WSQ-2: By 2004, ensure that all water quality segments within the estuary are in compliance with established dissolve oxygen criteria.

A second Objective that is partially supported by this monitoring is:

PH-3: By the year 2000, establish a contact recreation advisory program in all areas of the estuary used for contact recreation.

Conventional parameters are useful in characterizing a water body and can aid in the interpretation of other types of water quality parameter data. However, not all of the parameters listed are routinely analyzed under current monitoring programs.

For example, during most of the 20th century, a primary water quality concern was DO level as influenced by wastewater Biochemical Oxygen Demand (BOD) inputs. Accordingly, surface water samples have routinely been analyzed for BOD as if they were wastewater, using the multiple dilution technique specified in *Standard Methods* (APHA, 1992). Even up to ten years ago, it was common practice to run BOD analyses on bay water samples. As the level of wastewater treatment has increased, the effect of point sources on even tributaries to the bay BOD levels has become, in general, insignificant. Whatever anthropogenic source there may be is lost in the background BOD level of 1-4 mg/L produced by normal water column biochemical processes. Accordingly, the TNRCC has ceased performing BOD or CBOD (Carbonaceous BOD) analyses on bay water samples. A similar statement can be made for the Chemical Oxygen Demand (COD) test. However, in this case there is another reason to delete the test, namely the effect of chloride interferences on the COD test results.

The FC parameter is also subject to extreme variation in uses and analytical methods. There are two basic test methods for producing an FC result for a water sample. One is used by the Texas Department of Health (TDH) to regulate oyster harvesting waters and the other is used by all other agencies, primarily for detecting human health problems and addressing contact recreation concerns. Numerous studies (e.g., Jensen and Su, 1992) have confirmed that the two tests provide essentially equivalent information, yet the TDH, as mandated by the National Shellfish Sanitation Program, only accepts one of the methods (the one that is much more costly). The net effect is that the FC monitoring effort is somewhat inefficient.

As noted earlier, the primary use of the conventional parameters is general water quality characterization, including determining compliance with applicable criteria. Many agencies collect conventional water quality parameter data, generally as a part of their overall mandates. For example, the TNRCC monitors for several reasons including determination of criteria attainment and providing data for a report mandated by Section 305b of the Clean Water Act. Other agencies analyze conventional parameters for reasons such as identifying possible pollution problems or as a general characterization.

Another use of the conventional data is in providing information on trends of key parameters such as salinity, DO, or TSS. This trend information is quite useful in adjusting management directions and can play a major role in agency decision making. The ability to detect trends is strongly dependent on the number and frequency of observations, as well as the methods employed.

3.3.2 Sampling and Analytical Methods

By and large, the methods recommended for the conventional parameters are those which are currently employed by the many agencies involved. This is because there is already a great deal of experience in monitoring conventional parameters. DO, Temperature, pH, and conductivity/salinity are recommended to be measured with a probe, with a calibration check at the beginning and end of the sampling run. For laboratory analyses, Table 3-1 lists the recommended methods to be used. Changes

Table 3-1. COMPARABLE AND ACCEPTABLE LABORATORY ANALYTICAL METHODS FOR CONVENTIONAL WATER PARAMETERS*

Parameter	EPA Method	Standard Methods
CBOD5	405.1	5210
TSS	160.2	2540 D
VSS	160.4	2540 E
TOC	415.1	5310 B,C
Hardness	130.1, 130.2	2340 C
Chloride	325.3	
Sulfate	375.4	
FC		9222 D

* Parameters not measured by *in-situ* probe

and standardization of procedures would be required for some agencies, but the changes proposed are not large. It is expected that further evolution of methods will occur in the future.

Alternative Methods

There is at least one alternate approach or modification discussed which would serve to unify the data collection and integration process. The suggested alternative deals with the use of probe data logging, which would include time, depth, position (latitude/longitude) from a GPS unit, and the standard probe parameters. Additional parameters currently described under nutrients and phytoplankton monitoring (light via photometer and chlorophyll-*a* via fluorometer) could readily be added to the sampling probe system. With all of the data being recorded in a standard format, it would greatly facilitate the process of getting the data into a usable database. The capability of integrating the data collection, positioning and recording processes is relatively new and not commonly employed. However, it is well within the capability of commercially available equipment.

3.3.3 QA/QC Considerations

The QA/QC procedures recommended for monitoring conventional water quality parameters as part of the Galveston Bay Regional Monitoring Program are described in:

Quality Assurance Project Plan for Environmental Monitoring and Measurement Activities, Surface Water Monitoring. TNRCC, 1993.

They include requirements that 10% of samples be used for field duplicates and that strict field instrument calibration procedures be followed.

Quality control specifications for ambient water analyses have been incorporated into state law (*Texas Surface Water Quality Standards* Section 319.1 - 319.12).

These QC procedures (Table3-2.) are designed to satisfy EPA's National Pollution Discharge Elimination System (NPDES) monitoring program requirements. All laboratories performing NPDES work are required to use these QC procedures. It is recommended that, at a minimum, the QC standards for all Galveston Bay Regional Monitoring Program-related water, sediment, and tissue analyses also meet these legislated specifications.

3.4 NUTRIENTS

The elements which are intimately involved in biological processes, namely nitrogen (N), phosphorus (P), and silicon (Si), are usually considered separately as nutrient or macro-nutrient elements. While nitrogen is generally the chief limiting element to primary production in estuaries, phosphorus may be limiting during certain seasons of the year in some systems. Silicon is chiefly required by floral groups that secrete siliceous skeletons, but may be required by other aquatic plants as well. Silicon is most likely to have the potential to be limiting in lake systems or deeper bays such as Puget Sound. In relatively shallow Galveston Bay where sand and silicon containing minerals are in contact with the water, silicon is not likely to limit plant growth and therefore is not recommended as an indicator.

The concentration of nitrogen and phosphorus varies both spatially and temporally depending partly on the extent of plant growth and local inputs. Light transparency is another major factor involved in primary production in estuaries. In the ocean, below the depth at which plant growth is restricted by insufficient light, nutrient concentrations tend to be much higher and more uniform although there are significant variations in the different oceanic basins (Head, 1985).

The Galveston Bay Program candidate indicators for nutrients include the following parameters:

- Nitrogen
  - Ammonium–N
  - Nitrate-nitrite–N
- Phosphorus
  - Total
  - Ortho-phosphate
- Light penetration

Organic nitrogen (Total Kjeldahl N minus ammonium–N) is not considered for routine nutrient monitoring, although it is recommended to be measured in some samples. The phosphorus suite includes measurements of dissolved total phosphorus. With some samples, dissolved orthophosphate (PO_4^{3-}) should be analyzed. At some interval, a parallel set of unfiltered analyses should be performed. The candidate indicator for light penetration will be Secchi disk depth (see alternative methods).

Table 3-2. REQUIRED QUALITY CONTROL ANALYSIS

Parameter	Blank	Standard	Duplicate	Spike
Bacterial	A			B
Alkalinity			A	B
Ammonia Nitrogen	A	A	B	B
BOD	A	A	B	
BOD-Carbonaceous	A	A	B	B
Chloride	A	A	B	B
Cyanide-(total or Amenable to Chlorination)	A	A	B	B
pH		C		
Metals (all)	A	A	B	B
Nitrate Nitrogen	A	A	B	B
Nitrite Nitrogen	A	A	B	B
Orthophosphate	A	A	B	B
Oxygen (dissolved)		A	B	
Phosphorus-Total	A	A	B	B
Specific Conductance	A	A		
Sulfate	A	A	B	B
TOC	A	A	B	B
TSS	A		B	
TDS	A	A	B	
Organics by GC or GC/MS	A	A	E	E

A -Wherever specified, at least one blank and one standard shall be performed each day that samples are analyzed.

B -Wherever specified, duplicate and spike analyses shall be performed on a 10% basis each day that samples are analyzed. If one to 10 samples are analyzed on a particular day, then duplicate and one spike analysis shall be performed.

C -For pH analysis, the meter shall be calibrated each day that samples are analyzed using a minimum of two standards which bracket the pH value(s) of the sample(s).

D -For the oil and grease analysis and chlorine-total or free analysis, standards shall be analyzed on a 10% basis. If one to 10 samples are analyzed in lieu of standards for the oil and grease analysis and chlorine-total or free analysis.

E -For GC and GC/MS analyses, duplicate and spike analyses shall be performed on a 5% basis. If one to 20 samples are analyzed in a month, then one duplicate and one spike analysis per month shall be performed.

Source: *Texas Surface Water Quality Standards* - Sections 319.1 - 319.12

There are currently six agencies measuring nutrients in or near Galveston Bay. A summary of regional monitoring activities for Galveston Bay including agencies, data collection activities, parameters, methods, and QA/QC is presented in Table 1-1. TNRCC has the most comprehensive nutrient monitoring program involving 68 stations located throughout the bay. TNRCC routinely measures ammonium–N, nitrite–N, nitrate–N, total phosphorus, and orthophosphate. The City of Houston, Department of Public Utilities, currently measures ammonium–N in the tidal portions of major bayous in the Houston vicinity. The City of Houston, Health and Human Services Department, routinely measures ammonium-N and nitrate–N in streams in the Houston area. Although this monitoring effort is a significant one, the stations are all above tidal waters. The Harris County Pollution Control Department currently monitors ammonium-N at nine Houston Ship Channel stations, six San Jacinto River stations, and industrial and municipal dischargers. The Galveston County Health District monitors 120 stations in or near Galveston Bay at which they occasionally measure ammonium–N and total phosphorus.

3.4.1 Data Use and Limitations

The goal of nutrient monitoring is to provide data to assess GBP actions. To this end, the collection of nutrient data partially supports the following Resource Management Objectives:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014

WSQ-2: By 2004, ensure that all water quality segments within the estuary are in compliance with established DO criteria.

Nutrient data can be used to better interpret changes in plant growth and primary productivity. In the absence of another limiting factor such as light, an excess supply of nutrients can result in algal blooms and eutrophication of bay waters. A shortage of nutrients can lead to reduced productivity and decreasing numbers of important species. Monitoring nutrient levels in bay waters will provide information needed to:

- characterize ambient nutrient levels
- explain and identify potential causes for observed changes in plant species composition, growth, and/or distribution
- predict the location and timing of algal blooms or shortfalls.

Nutrient monitoring will also allow an evaluation of whether the following Galveston Bay Program management action is being achieved:

- reduce contaminant concentrations to meet standards and criteria

One of the major limitations of bay monitoring of nutrients is obtaining sufficient observations to adequately characterize a system with large spatial and temporal variations. The Galveston Bay Program monitoring approach, which seeks to involve city and county agencies in addition to the TNRCC is a way to achieve greater sampling density.

3.4.2 Sampling and Analytical Methods

A special study by Ward and Armstrong (1992) was sponsored by the Galveston Bay National Estuary Program to compile data from various organizations and to perform a quantitative assessment of water and sediment quality of Galveston Bay over time. The study characterized the concentrations and distribution of parameters throughout Galveston Bay. In regard to nutrients, the study revealed declines in nitrogen and phosphorus concentrations throughout the bay over the past two decades: total ammonium-N on the order of 0.1 ppm/yr, total nitrate-N on the order of 0.01 ppm/yr, and total phosphorus on the order of 0.05 ppm/yr. This decline in nutrients is a concern to the estuarine ecosystem. Ward and Armstrong (1992) suggest that the total suspended solids (TSS) decline is caused by an overall reduction of loading to the bay. They feel this resulted from more advanced waste treatment, entrapment within reservoirs, and changing land use. Because nitrogen and phosphorus have an affinity for fine-grain particulates, their declines may be due to the same causes. This study emphasizes the importance and provides the foundation for further scientific study of nutrients in Galveston Bay.

Recommended Methods

The current methods for nutrients incorporated by the various agencies monitoring in Galveston Bay include:

> *Methods for Chemical Analyses of Water and Wastes.* EPA 600/4-79-020. Cincinnati, OH. US Environmental Protection Agency, 1983, and
>
> *Standard Methods for the Examination of Water and Wastewater.* APHA, 1992.

As mentioned, TNRCC conducts the most extensive nutrient monitoring in which they utilize USEPA (1983) methods.

The sampling of Bay waters for nutrient analysis presents no particular problems if normal standards of cleanliness are maintained. Samples should be collected in glass or plastic containers with leak-proof caps. If plastic containers are used more than once, they should be acid-washed to remove bacteria. In the field, samplers and containers should be thoroughly rinsed with water similar to that to be sampled before each sample is taken. These precautions are particularly important in estuaries, where major changes can occur over relatively short distances and depth ranges (Head, 1985). Samples and sampling containers should not be touched with ungloved fingers. Filtration should be carried out in the field or as soon as possible after collection. Samples can be stored for up to 28 days by cooling at 4° C and adding sulfuric acid to a pH < 2. Nitrate-N samples should be analyzed immediately after collection, or within 48 hours by cooling at 4° C. Water clarity should be measured routinely in the field via photometer or Secchi disk.

The methods recommended in Table 3-3 for the major nutrients are currently employed and generally workable methods. However, they should not be viewed as mandated by the Galveston Bay Program. In fact, the key requirement is that whatever methods are employed can demonstrate the necessary accuracy and precision. If an agency desires to use an alternate method and provides information to the TNRCC supporting this method, there should be no difficulty in substitution.

Table 3-3. COMPARABLE AND ACCEPTABLE LABORATORY ANALYTICAL METHODS FOR NUTRIENT PARAMETERS

Parameter	EPA Method	Standard Methods
Ammonium-N	350.1*, 350.3	4500-NH3 D,F,H
Nitrate-nitrite	353.1, 353.2* 353.3	4500-NO3 C,D E, F
Phosphorus (all types)	365.1, 365.2 365.3, 365.4	4500-P D, E, F

*recommended procedures for NEPs (USEPA, 1992)

Alternative Methods

The possible effects of nutrient limitation as well as excess must be addressed. Therefore, the need for greater sensitivity should be considered. The methods described for nutrients in Parsons et al. (1984) can provide greater sensitivity, as well as precision and accuracy. These methods are currently used in the Puget Sound Water Quality Monitoring Program, but are not used in any existing monitoring effort in the Galveston Bay region. The cost of these more sensitive analyses would be greater than existing methods. However, since there are no commercial laboratories providing this type of service, no direct cost comparison is available.

Another recommendation would involve analyzing unfiltered (i.e., dissolved and particulate) inorganic nitrogen and phosphorus at some interval, such as every 10 samples, for some stations. A greater sensitivity and measurements of the full nitrogen and phosphorus suites would greatly enhance the knowledge of nutrient limitations and provide a foundation for future nutrient quantitative work in Galveston Bay.

The use of an in-situ calibrated photometer for the measurement of light transmission in Galveston Bay should be considered in place of the Secchi disk. The current use of a Secchi disk has several limiting factors. Because Secchi disk readings are dependent upon the available illumination, they vary with cloud cover, cloud formation, and time of day. Secchi disk readings may also vary with the observer because of differences in visual acuity. Thus, to standardize these readings, repeated measurements should be made by one individual under similar conditions of illumination. The Secchi disk is recommended because it is currently being used by the TNRCC and data comparability would be continuous.

Since the regional monitoring plan recommends that primary production be estimated based on known relationships between irradiance and photosynthesis, a more accurate and reliable measurement of light should be considered. A photometer provides a direct reading of light intensity with depth. It could be incorporated into the normal probe package and recorded automatically at little extra cost. Considering the reduced labor cost of avoiding the Secchi disk measurement and manual data entry, it could be a net savings. Absolute light intensity readings should be automatically recorded at the 30-centimeter, 1.5-, and 3-meter intervals with readings at 3-meter increments at greater depth. The result would be far better quality data at little difference in cost. However, an overlap period would be necessary during which both instruments were used to obtain a between instrument calibration.

3.4.3 QA/QC Considerations

The QA/QC procedures for nutrient sample collection and handling as part of the Galveston Bay Regional Monitoring Program are described in:

Water Quality Monitoring Procedures Manual, Draft. TWC, 1993 and

Quality Assurance Project Plan for Environmental Monitoring and Measurement Activities, Surface Water Monitoring. TNRCC, 1993.

In addition, the Galveston Bay Program is planning to organize an annual workshop for agency personnel involved in sample collection activities. This workshop will provide training in standardized sample collection methods and provide an opportunity to disseminate updated methods as they become available. This training will cover collection, preservation, and shipping of routine water quality samples.

At a minimum, analytical QC procedures should meet the NPDES monitoring program requirements as set out in the *Texas Surface Water Quality Standards* Section 319.1 - 319.12 (Table 3-2).

Additions to the existing QA/QC procedures should be considered as presented in:

Monitoring Guidance for the National Estuary Program. EPA 823-R-93-002. US Environmental Protection Agency, 1992.

Calibration standards should be analyzed at the beginning of sample analysis, and should be verified at the end of each 12-hour shift during which analyses are performed (USEPA, 1987). Spike recovery analyses are required to assess method performance for the particular sample matrix. Recommended control limits include 75-125 percent recovery for spikes, and 80-120 percent recovery for the analysis of standard reference materials. A minimum of 5 percent of the analyses should be laboratory replicates. The control limits are +/- 20 percent variation between duplicates. Triplicates should be analyzed on one of every 20 samples or on one sample per batch if less than 20 samples are analyzed.

3.5 TOXIC PARAMETERS

The broad heading of toxic parameters is commonly used to refer to trace metals and organic substances which could possibly exert a toxic effect, if present in sufficiently high concentrations or if present for a sufficient length of time to bioaccumulate to toxic levels.

The candidate indicators for toxic parameters derive from several lists which have been generated by various agencies. Examples include the early "Priority Pollutant List" or the Appendix IX list (40 CFR 264) used in hazardous waste regulation, both produced by EPA, and the parameters specified in the *Texas Surface Water Quality Standards* for Aquatic Toxicity and Human Health protection. The lists can be further subdivided into organic and inorganic portions. The inorganic portion is almost entirely limited to the so-called "trace" metals, i.e., those which exist naturally in relatively low concentrations but if introduced in markedly higher concentrations can have a deleterious effect. The organic substances include both those common industrial organic compounds such as solvents and fuels, and also those compounds designed specifically for a toxic effect, i.e., pesticides.

There are also a number of organic compounds which were not designed for toxicity but still have the effect. Examples would include PCBs and dioxins. Finally, there is a broad class of organic compounds referred to as Polycyclic Aromatic Hydrocarbons (PAHs). Most of these are combustion byproducts and can accumulate in tissue. They can be a concern both from a toxicity and carcinogenicity perspective. Those with less than four aromatic rings tend to be water soluble and relatively toxic (e.g. naphthalene) while the larger molecules (four rings or greater) are not soluble or toxic but have demonstrated carcinogenicity in the laboratory. While not necessarily toxic to marine life, they can pose a human health concern from consumption of the marine life. Most come from combustion sources, and are common in many foods. Those which come from crude oil tend to be those with the smaller number of rings and with more alkyl substitutions on the ring structure.

One of the key concerns with monitoring for toxic substances is the difficulty of detection in the water column. In general it is very difficult to detect and quantify significant concentrations in the water column, unless one is sampling in the immediate area of a point source discharge where the concentrations are unusually high. Because of this limitation, most monitoring for toxic substances is directed at sediments and organism tissues. Examples include NOAA's National Status and Trends Program (NSTP) and the EPA's EMAP program. The oyster is widely used as an indicator organism because it filters large amounts of water and can concentrate toxic substances, particularly those in particulate form, in its tissue. Because many potentially toxic substances tend to sorb to particulate matter, the sediments tend to have higher concentrations, thus allowing easier detection. Monitoring toxic parameters in sediment and tissue is discussed in separate sections of this document. The key point here is that monitoring toxic substances in the water column may not be the most effective approach (i.e., result in any significant detections). However, two Resource Monitoring Objectives, WSQ-1 and WSQ-2, require that water toxicity be monitored to support the determination that water quality does not exceed regulatory criteria and that ambient water toxicity be eliminated.

3.5.1 Data Use and Limitations

Monitoring toxic contaminants in the water column will provide information needed to assess the effectiveness of Galveston Bay Program Management actions. It will also support determinations of whether the following Resource Monitoring Objective:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediment by 2014

In addition to supporting these objectives, another purpose of monitoring toxic substances is to provide an assurance that there are no additions or changes in parameter concentrations that could induce new toxicity to the system.

The major limitation that exists is typically the analytical methods, particularly for the inorganic parameters. For example, many of the trace metals have specified regulatory criteria that are substantially lower than the minimum analytical level (MAL) of the most sensitive commercially available technique. In addition, working at very low ambient concentrations, it is frequently possible for false detections to occur from interference by a range of factors including sea salts. The result is that comparisons of this type have generated false detections in the past which resulted in considerable effort being expended. Later and better quality data have demonstrated that these concerns were misplaced, even with the very conservative numerical toxics criteria.

3.5.2 Sampling and Analytical Methods

There are several ongoing routine monitoring programs for toxic substances in the water column. These include the TNRCC, the US Army Corps of Engineers' Dredged Material Monitoring Program, and the EPA's EMAP and R-EMAP-TX programs. In addition, there have been a number of special studies conducted in the last several years which provide information on the concentrations of toxic parameters in the water column. The TNRCC procedures (TNRCC, 1993) involve selected stations and use of inductivity coupled plasma (ICP) spectroscopy methods for metals (6010 series) and 608/8080 methods for organics. The Corps monitors water from above areas to be dredged (as well as bulk sediment and elutriate concentrations) for metals and major pesticides and PAHs. The metals are analyzed using Graphite Furnace AA, and the organics using 8000 series EPA methods.

Recommended Methods

The methods recommended for trace metals and organic parameters differ substantially. Table 3-4 summarizes the acceptable methods for analysis of water samples.

In the case of the organic parameters, the EPA methods are the same that are currently being used by all monitoring programs. In that case, the selection criteria of comparability, cost, sensitivity, accuracy and precision all would favor the recommended method. For trace metal analyses the criteria of comparability is difficult to evaluate since the TNRCC, Corps and other federal efforts all use different analytical procedures. Furthermore, these procedures have evolved substantially over the last 10 years. There is no question that the cost criterion favors the TNRCC ICP methods. However, this is also the least accurate method and is of questionable value in marine waters. From the standpoint of sensitivity, accuracy and precision, the ultra-clean approach is a possible option.

Table 3-4. COMPARABLE AND ACCEPTABLE LABORATORY ANALYTICAL METHODS FOR TOXIC PARAMETERS

Parameter	EPA Method	Standard Methods
Dissolved metals	AA Furnace	3113 B ICP-MS
Mercury	245.1, 245.2	3500 Hg-B 245.5 (Sediment)
Volatile organics	624, 1624	6220 B
Acid-base neutral organics	625, 1625	6410 B, 6440
Pesticides	608, 625	6410 B, 6630 B,C

Alternative Methods

For trace metals, the so-called "ultra clean" procedures currently employed by Texas A&M University's Trace Element Research Laboratory and used in analyses for EMAP, NOAA NSTP and USFWS monitoring are a possible alternative method (GERG, 1990). The essential components of the ultra clean methods are to avoid sample contamination by carefully selecting and cleaning the collection equipment, sampling well away from the influence of a boat, and filtering either in the field or shortly thereafter with specially prepared equipment. With environmental contamination minimized the next major component of the work is extreme care in the use of laboratory equipment. If levels are below that which a spike can be accurately recovered from the water, any of several extraction techniques must be used to increase the concentration to the point where a reliable measurement can be made. A key component of this laboratory work is rigorous testing and cross-checking for contamination and instrument drift. The level of care must be unusually high in saltwater samples because of the presence of metals such as sodium and magnesium at levels many orders of magnitude greater than that of the trace metals being researched. However, although the collection techniques are straightforward, laboratory methods are more demanding than methods presently being used by participating laboratories.

3.5.3 QA/QC Considerations

Quality control specifications for water analyses have been incorporated into state law (*Texas Surface Water Quality Standards* Sections 319.1 - 319.12), as summarized in Table 3-2. Although designed to satisfy National Pollution Discharge Elimination System monitoring requirements, these specifications are considered appropriate for routine ambient water quality analyses. All laboratories conducting analyses for the Galveston Bay Program will follow these QA/QC procedures.

In addition, the Galveston Bay Program is planning to organize an annual workshop for agency personnel involved in sample collection activities. This workshop will provide training in standardized sample collection methods and provide an opportunity to disseminate updated methods as they become available.

CHAPTER 4
SEDIMENT QUALITY

Galveston Bay is the eventual repository for chemicals that are either discharged directly into the bay or delivered by rivers and streams that feed into the bay. Bay sediments represent the ultimate sink for many chemical toxics in the estuarine environment (USEPA, 1992). Bay sediments also represent an important habitat for many commercially, recreationally, and ecologically important organisms. A recent characterization report has documented declining trends in selected living resources (Loeffler and Walton, 1992). It is suspected that the introduction of anthropogenic contaminants into the Galveston Bay estuary is a major factor in the decline in species diversity and productivity that has been observed in areas of the estuary (Bechtel and Copeland, 1970; Copeland and Bechtel, 1971; Loeffler and Walton, 1992). However, ecological effects due to contaminants have been extremely difficult to distinguish from other human activities and natural variability (Luoma and Phillips, 1988; Loeffler and Walton, 1992). Sediment quality monitoring can provide information to evaluate potential stresses to estuary biota due to the presence of sediment contaminants, identify degrading benthic habitats, and track habitat recovery following environmental remediation actions.

A triad approach to sediment evaluation has been selected for the Galveston Bay Program. The sediment quality triad is intended to incorporate three essential types of data to define pollution degraded areas: measurements of (1) anthropogenic chemical contamination (i.e., bulk sediment chemistry), (2) toxicity to organisms (i.e., sediment bioassays), and (3) effects on resident infaunal communities (i.e., changes in infaunal community structure). It has been demonstrated that each data type alone is insufficient to demonstrate impacts to benthic communities due to sediment contamination (Chapman et al., 1987). Bulk sediment chemistry and physical measurements provide information on the amount and bioavailability of chemicals, but does not describe effects to communities. Bioassays provide information on sediment effects to selected laboratory organisms, but does not test field conditions of exposure by resident communities. Benthic community structure data provides information on effects to resident communities, but alone cannot relate changes in community structure to sediment contamination — alterations in community compositions may be due to sediment grain size, competition, predation, recruitment, salinity, and other factors. In addition, identification of pollution degraded areas based solely on alterations in community structure are usually difficult due to the high degree of variability in the structure of natural communities.

Sediment quality monitoring will provide information useful for evaluating the effectiveness of the following Galveston Bay Program Management Action:

- Reduce toxicity and contaminant concentrations in water and sediments.

A determination of whether the following Resource Management Objective is being attained will also be supported with this monitoring data:

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014

This chapter describes methods for sampling and analyzing Galveston Bay sediments and the benthic infauna they support. The chapter is divided into the following monitoring topics:

Section 4.1	Sediment Collection
Section 4.2	Sediment Grain Size
Section 4.3	Benthic Infauna Identification and Enumeration
Section 4.4	Sediment Toxics
Section 4.5	Sediment Bioassays.

4.1 SEDIMENT COLLECTION

To mitigate the costs of field sampling and to permit valid correlation and multivariate analyses, it is recommended that sediment samples for chemical, toxicological, and benthic infauna analyses be collected simultaneously. Although sediments collected for sediment chemistry and toxicity analyses and sediments designated for benthic community analyses could be collected using different sampling devices, using one sediment sampling device simplifies sample collection activities.

4.1.1 Data Use and Limitations

Sediment samples are collected for grain size analysis, chemical analysis, benthic infauna investigations, or to be used in sediment bioassay testing. Data use and limitations vary according to the parameter collected for analysis and are discussed in detail in the following sections.

4.1.2 Sampling and Analytical Methods

A wide variety of sediment collection techniques are available. However, for the purposes of monitoring in Galveston bay to support the Resource Management Objective and action noted above, most collection activities will be concerned with only the top few centimeters of sediment. Many types of sediment dredges or grab samplers are available for sampling from vessels and by hand. For example, TNRCC use an Ekman dredge; the EMAP protocols call for a Young-modified van

Veen grab sampler; the US Army Corps of Engineers use sediment corers capable of penetrating the sediment to proposed construction depths because of the regulatory requirement to test the entire sediment column; NOAA specifies a Smith-McIntyre grab, a box corer, or a van Veen grab, depending on the program (Benthic Surveillance or Mussel Watch); and the USFWS use a 10-cm (4-inch) diameter corer to sample to depths of 7.5-10 cm.

Recommended Methods

It is recommended that sediment samples for different types of analyses be collected simultaneously and that one type of sampling device be used for monitoring purposes. An Ekman dredge, as used by TNRCC is the recommended device. This dredge is versatile, can penetrate and collect sufficient volume of sediment for nearly all requirements (except for proposed dredging material), and it is relatively simple to operate correctly.

For each sampling event, the sample should be evaluated to determine whether the following sample acceptability criteria are met:

- Sampler is not over-filled with sample so that the sediment is pressed against the top of the sampler
- Overlying water is present, indicating minimal leakage
- Overlying water is not excessively turbid indicating minimal sample disturbance
- Sediment surface is relatively flat and level with the sampler indicating minimal disturbance or winnowing
- Desired penetration depth is achieved — at a minimum, the aerobic layer should be sampled because this zone is where most of the benthic infauna live and includes the most recent sediment deposition (Day et al., 1989; USEPA, 1992; Loeffler and Walton, 1992).

If the sample does not meet these criteria, resampling is required. If the sample meets these criteria, gently decant all the overlying water, taking care not to remove surficial sediments.

The aerobic layer of bottom sediments can usually be identified based on color (TWC, 1993) and homogenized to assess average infaunal exposure to sediment contaminants. The depth of the aerobic layer will be recorded in the field notebook. If the aerobic layer is less than 2 centimeters, as it can be in portions of the upper Houston Ship Channel during the summer, the upper 2 centimeter will be collected and homogenized.

Once the sample is transferred from the dredge to a sample container, seal and label the container with the station identification code, date, and type of analyses requested (e.g., metals analysis). For each sample, the following information should be recorded in the field notebook:

- Sample identification code
- Name of collector
- Location
- Date
- Time
- Habitat
- Water depth
- Weather conditions
- Number of grabs composited

- Sample description
  - color
  - odor
  - presence of sheen
  - consistency/texture
  - gross grain size
  - obvious organisms or plants, and unusual objects

At a minimum, 300 mL of sediment is required; 500-800 mL of sediment is preferred. Recovering sufficient sample volume usually will not present a problem because of the capacity of the sampler. A portion of the sample will undergo sediment chemistry analyses; the other portion will be used to conduct sediment toxicity tests.

A minimum of three replicate samples are recommended to be collected at each station and composited to form the final sample. Separate samples will be collected for benthic community assessment. Analysis of historical data indicate that a minimum of four replicate Ekman grabs should be used for benthic community assessment (G. Guillen, TNRCC, personal communication).

More detailed information on sampling procedures can be found in:

Water Quality Monitoring Procedures Manual. Draft. TNRCC (TWC), 1993.

4.1.3 QA/QC Considerations

When collecting sediment samples for chemical analyses or toxicity tests, avoid airborne (e.g., engine exhaust, cigarette smoke) and other sources of contamination. All sampling equipment (e.g., siphon hoses, scoops, containers) must be made of noncontaminating material and cleaned prior to use. Wear clean gloves when touching samples or sampling containers. Standard clean techniques are used to store, transfer, and process sediments. All samples are stored in clean USEPA approved containers and placed in the dark at less than 4° C until delivery to the laboratory. More detailed QA/QC considerations are discussed in the following sections.

4.2 SEDIMENT GRAIN SIZE

Grain size is used to characterize the physical characteristics of estuarine sediments. The availability of sediment contaminants and organic content are often correlated with sediment grain size. Because grain size influences chemical variables, it can be used to normalize chemical concentrations. Accordingly, grain size is an essential element of sediment sampling and analysis.

4.2.1 Data Use and Limitations

Grain size data often explain the temporal and spatial variability in biological assemblages; changes in sediment grain size often affect an infaunal organism's ability to build tubes, capture food, and escape predation. Grain size can be used to account for some of the variation found in biological assemblages.

Grain size data may be used to:

- Monitor rates of recovery following environmental interventions
- Evaluate the condition of benthic habitats
- Assist in providing early warnings of potential impacts to the estuarine ecosystem.

Sediment grain size composition is often temporally stable, although some slight seasonal variability may be present. Changes are usually associated with seasonal patterns of benthic turbulent mixing and sediment transport phenomena. The frequency of sampling should be related to the expected rate of change in grain size composition. A consistent sampling period is recommended in order that spatial and temporal comparisons may be conducted.

4.2.2 Sampling and Analytical Methods

Recommended Methods

Recommended sampling techniques are discussed in Section 4.1 (Sediment Collection). If seasonal variations are exhibited, it is recommended that direct comparisons between samples collected during different seasons be avoided. Studies investigating interannual variation in the grain size composition should conduct sampling during the same season (preferably the same month) each year.

Sediment grain size may be expressed in either millimeter (mm) or j (phi) units. These scales are related according to the equation:

$j = -\log_2 (mm)$

Data should be converted to phi units before calculation of grain size parameters. Sediments are broadly classified into three size classes: silts and clays are less than 0.064 mm (4 j) in diameter, sands range from 0.064 mm (4 j) to 1 mm (0 j) in diameter, and gravels are larger than 1 mm. Grain size is normally reported as the mean, although the median grain size is sometimes used. Sorting is a measure of the spread of the grain size distribution.

NOAA's *Sampling and Analytical Methods of the National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984-1992* (NOAA, 1993) NOS ORCA 71 and
EMAP Estuaries Laboratory Methods Manual. (USEPA, 1993) EPA/600/4-91/024, provide a review of the methodological and statistical analysis of sediment grain size.

Particle size determination can either include or exclude organic material. If organic material is removed prior to analysis, the "true" particle size distribution is determined. If organic material is included in the analysis, the "apparent" particle size distribution is ascertained. Most organic material is in the silt/clay size range and can be removed from the sediment either by acid washing or ashing. If organic material is left in the sediments, it will tend to bias the results toward a smaller mean size. Because true and apparent distributions differ, detailed comparisons between samples analyzed by these different methods are questionable. It is therefore recommended that measures of sediment grain size be examined using only one of these methods. A standardized grain size analysis will allow all comparisons between samples.

Particle-size analysis of a sediment sample will often require the use of two or more methods because of the wide range of particle sizes encountered. Sieves are recommended for separation of the coarser fractions, electronic particle counters or pipette methods for the finer particle fractions. Detailed instructions for both methods are presented in Plumb (1981) and PSEP (1986).

4.2.3 QA/QC Protocols

It is recommended that triplicate analyses be conducted on one of every 20 samples, or on one sample per batch if less than 20 samples are analyzed. It is also recommended that the analytical balance, drying oven, and temperature bath be inspected daily and calibrated at least once per week. More detailed QA/QC procedures are outlined in the two references cited above and in Plumb (1981) and PSEP (1986).

4.3 BENTHIC INFAUNA SAMPLING

Benthic infauna are important mediators of nutrient cycling and important prey for species at higher trophic levels — especially for large epibenthic invertebrates and fish, many of which are of recreational or commercial importance. Benthic infauna are also exceptional indicators of benthic conditions because they:

- Are generally sedentary — observed effects are in response to local environmental conditions

- Are sensitive to habitat disturbance — communities undergo dramatic changes in species composition and abundance in response to environmental perturbations

- Often mediate the transfer of energy and toxic substances in the ecosystem — via bioturbation and as important prey organisms

Benthic infauna monitoring will provide information to support a determination of whether the following Resource Management Objectives are being attained:

HP-5: Restore natural functions and values to 50 percent of degraded wetlands within 20 years

WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014.

Monitoring of the benthic community will also support evaluation of progress towards the Species Population Protection Management Goal:

- Reverse the declining population trend for affected species of marine organisms, and maintain the populations of other economic and ecologically important species.

4.3.1 Data Use and Limitations

Benthic infauna community data can provide *in situ* measures of sediment quality and biotic condition. In addition to assessing sediment quality, the collection of benthic infauna data serves a number of uses, including assessing wetland quality and determining the condition of estuary biota.

Recommended measurements of community structure include:

- Biomass
- Number of individuals
- Number of species
- Species dominance
- Abundance of contaminant-sensitive species
- Abundance of opportunistic and contaminant-tolerant species.

Typically, areas of severely degraded sediment quality are characterized by low numbers of individuals and species. Highly degraded areas are dominated by a few, highly-abundant populations of small-bodied opportunistic or contaminant-tolerant species. Areas of superior sediment quality are characterized by many small populations of competitively dominant species (Pearson and Rosenberg, 1978). These measures of community structure have proved useful over various habitats and regions (USEPA, 1992).

4.3.2 Sampling and Analytical Methods

Directly relating changes in benthic communities to levels of sediment-adsorbed contaminants has been difficult because infauna appear to be highly sensitive to a number of dynamic physical and chemical factors. Of significant importance is their sensitivity to changes in grain size — some benthic organisms appear to be more sensitive to changes in sediment grain size than to concentrations of sediment-adsorbed contaminants (Long et al., 1990). To accurately explain changes in the distributions or loss of specific benthic organisms, measurements of grain size in conjunction with concentrations of sediment contaminants must be collected.

Infaunal sampling is normally performed with either an Ekman dredge, Surber sampler, or kicknet, depending on the water depth and substrate type. Although, other types of grabs have been used for sediment sampling (see section 4.1.2), an Ekman dredge, as used by TNRCC, is recommended for both sediment collection and benthic sampling.

Recommended Methods

Collection Procedures: For consistency in sampling through the Ekman dredge is recommended as the preferred sampling mechanism. Field procedures for the Ekman dredge are described in Section 4.1.

Wash sediments overboard through a sieve bucket, mesh size 0.5 mm, by dunking the bucket gently. Wash material retained on bucket screen onto a wide-mouthed container. Check the screen for organisms trapped in or wound around the mesh wires and back-wash the screen into the container with a high pressure spray to dislodge any sediment grains that may be caught in the mesh. Add relaxant (7 percent Mg_2Cl in sea water) to a depth of 3 cm, completely covering the sample (narcotization of the sample will aid in the subsequent identification of soft-bodied species).

After the sample has been narcotized for at least 0.5 to 1 hour, add a 10 percent borax-buffered formalin solution to the sample container — samples containing large amounts of fine grained sediments, peat, or wood plant material may require higher concentrations. The volume of the fixative should be at least twice the volume of the sample. Rose-bengal can be added to the formalin solution to assist in separating organisms from sediment in the laboratory. Add the fixative solution until the container is completely filled to minimize abrasion during shipping and handling. Label the sample bottle with the name of the collector, station number, date, time, number of dredges composited, depth of collection, and preservative used. Store samples in the dark at moderate temperatures. After being stored for approximately 1 hour, samples should be inverted several times to ensure adequate mixing.

The following information should be recorded in the field notebook at the time of sampling:

- Sample identification code

- Name of collector
- Location
- Date
- Time
- Habitat
- Water depth
- Weather conditions
- Type of sampler used
- Preservative used
- Sample description
  - area and volume of sample
  - effort and duration of the sampling effort
  - color
  - odor
  - presence of sheen
  - consistency/texture
  - gross grain size
  - obvious organisms or plants, and unusual objects.

This procedure is described in more detail in *Water Quality Monitoring Procedures Manual. Draft.* TWC, 1993.

Laboratory Procedures: Sort, identify, and enumerate organisms found in the sample in the laboratory within two weeks, and preserve in 70 percent ethyl alcohol solution. Samples should remain in the formalin-seawater solution for a minimum of 24 hours to allow proper fixation; a maximum fixation period of 7 to 10 days is recommended to reduce the risk of decalcifying molluscs and echinoderms. After fixation, wash samples on a sieve with mesh openings half the size (at most) of those used in the field. For long-term storage of crustaceans, substitute glycerine for some of the water (70 percent ethyl alcohol, 25 percent water, 5 percent glycerine). Glycerine keeps the exoskeleton supple, facilitating examination and manipulation.

Gently flush the sample with large quantities of fresh water, being careful not to splash any sample material. Allow rinse water to completely drain from the sieve and lightly rinse the sample with a 70 percent ethyl alcohol solution. Wash sample into a sample jar filling it no more than three quarters full. Rinse the last bit of material into the jar using a squirt bottle. Fill the jar with 70 percent ethyl alcohol. Gently shake and invert jar to ensure mixing.

Using a 10x power dissection scope, systematically sort the sample by removing each organism and placing it into a petri dish. Care must be taken that enough liquid is present in the petri dish to completely cover the sample. Sort each petri dish twice to ensure that all organisms are removed. Using an analytical balance, measure biomass by taking the difference between a beaker filled with preservative before and after organisms are placed in the beaker. Do not blot organisms prior to weighing. This technique appears to introduce the least amount of variation into the weighing process.

After biomass estimates are completed, identify and count organisms. Unless otherwise specified, identifications should be to the lowest practical taxonomic unit. Generally, it is necessary to only speciate the dominant organisms. If possible, at least two references should be used for each species identification. Moreover, each species identification should be checked against a reference specimen from a verified reference collection. After completing taxonomic identification, place all organisms in vials containing 70 percent ethyl alcohol solution. Label each vial (see reporting information given above). Store all vials for a single sample in common jars and immersed in 70 percent ethyl alcohol solution.

Each taxonomist should initial identifications and counts in a notebook which also include notes and comments on the organisms in each sample. Have the taxonomists sign and date sample data sheets.

4.3.3 QA/QC Protocols

Sample Analysis: It is recommended that at least 20 percent of each sample be re-sorted for QA/QC purposes. Re-sorting is the examination of a sample that has been sorted once and is considered free of organisms. Re-sorting should be conducted by an individual other than the one who sorted the original sample. To ensure that identifications are correct, 5 percent of all samples identified by one taxonomist should be re-identified by another taxonomist.

Send at least three individuals of each taxon to recognized experts for verification. Place the verified specimens in a permanent reference collection. Label all specimens in the reference collection and segregate by species and sample. Archive reference specimens alphabetically within major taxonomic groups. Have the laboratory staff participate in a regional taxonomic standardization program (if available) to ensure regional consistency and accuracy of identifications.

At a minimum, calibrate the analytical balances used for biomass determinations weekly. Service all balances and microscopes at regular intervals. Annual service and inspection is adequate in most cases, unless the manufacturer recommends otherwise.

4.4 SEDIMENT TOXICS

The parameters of primary concern in sediments include the full range of organic substances designed to control undesirable organisms (e.g., insecticides, fungicides, etc.), a range of organic substances that were not intended to be toxic as a product but which have toxic effects (e.g., PCBs, dioxin, tributyltin, etc.), a wide range of organic compounds associated with development (e.g., polycyclic aromatic hydrocarbons, etc.) and trace metals. All of these are particle-adsorbing to some degree, making them tend to be concentrated in areas of recent sediment deposition. As a result of being concentrated, it is much easier to detect the substances in the sediment. For that reason, most efforts at toxics monitoring are focused on sediment analyses, with enough water analyses to provide an accurate documentation of levels and to assure the absence of a problem.

Sediment monitoring is routinely performed in Galveston Bay by both the TNRCC and by the Corps of Engineers. In addition, a wide range of special studies of sediment characteristics are conducted by several federal agencies (NOAA Status and Trends; USEPA EMAP). The TNRCC monitors a wide range of stations while the Corps concentrates on sediments in navigation channels that are proposed for dredging.

The list of chemicals of concern for the Galveston Bay Program is based on those selected by the USEPA EMAP program (Table 4-1). This will provide a comparison of results against the EMAP data for consistency and will provide some additional data for the evaluation of Resource Management Goals.

4.4.1 Data Use and Limitations

The collection of bulk sediment chemical data will be used to support the evaluation of the following Resource Management Objective:

> WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014,

and the effectiveness of associated Galveston Bay Plan Management Actions:

- Reduce contaminant concentrations to meet standards and criteria
- Determine sources of ambient toxicity in water and sediment.

Parameters for the measurement of sediment toxicity have been selected to determine the effectiveness of actions related to the Resource Management Objective. Information on concentration levels is needed to assess the trends in toxicity and the possible effect of elevated concentrations on the living resources within Galveston Bay. Determinations of sediment contaminant levels, along with bioassay testing and benthic community evaluations will provide information needed to assess the effects on living resources.

The primary limitation is that while a wide range of substances which are potentially toxic tend to adsorb to particles and accumulate in the sediment, the actual biological effect of such materials is highly variable due to the chemical form of materials in the sediment and the effect of natural complexing agents. The net effect is that it is quite difficult to define relationships between toxic concentrations in sediments and biological effects. Alternatives, including bioassay testing for particular purposes such as dredged material disposal, and benthic assessments of ambient sediments, are discussed under Alternative Methods.

Table 4-1. SEDIMENT CONTAMINANTS OF CONCERN FOR THE GALVESTON BAY PROGRAM

PAHs

Acenaphthene
Acenaphthylene
Anthracene
Benzo(a)anthracene
Benzo(a)pyrene
Benzo(b)fluoranthene
Benzo(e)pyrene
Benzo(g,h,i)perylene
Benzo(k)fluoranthene
Biphenyl
Chrysene
C1, C2, C3, C4 Chrysene
Dibenzo(a,h)anthracene
Dibenzothio
C1, C2, C3-dibenzothio
Fluoranthene
C1-fluoranthpyrene
Fluorene
C1, C2, C3-fluorene
Naphthalene
C1, C2, C3, C4-naphthalene
Perylene
Phenanthrene
C1, C2, C3, C4-phenanthrene
Pyrene
1,2,3-c,d-pyrene
1-methylnaphthalene
2-methylnaphthalene
2,3,5-Trimethylnaphthalene
2,6-Dinethylnaphthalene
1-methyulphenanthrene
High Molecular Wt. PAH's
Low Molecular Wt. PAH's
Total PAH's

PCBs

Pesticides

2,4'DDD
4,4'DDD
2,4'DDE
4,4'DDE
2,4'DDT
4,4'DDT
Aldrin
alpha-BHC
beta-BHC
delta-BHC
alpha-chlordane
gamma-chlordane
Dieldrin
Endrin
Heptachlor
Heptachlor epoxide
Methoxychlor
Lindane
Toxaphene
Malthion
Parathion
Diazinon
Endosulfan
Mirex
Total BHCs

Inorganics

Aluminum
Antimony
Arsenic
Cadimum
Chromium
Copper
Iron
Lead
Manganese
Mercury
Nickel
Selenium
Silver
Tin
Zinc
Tri-butyl tin

4.4.2 Sampling and Analytical Methods

Monitoring of selected parameters in sediments is required under the Galveston Bay Plan and will be performed. However, because part of the reason that sediment chemical (toxics) monitoring is conducted is to try to explain some observed degradation of a sediment, it is recommended that sediments be examined concurrently for the health and diversity of the benthic community and for toxicity effects on appropriate indicator species.

Recommended Methods

Table 4-2 provides a list of analytical techniques for metals and organic compounds and the respective EPA Method numbers. Methods for sediment analyses are

Table 4-2. LIST OF EXISTING ANALYTICAL TECHNIQUES (U.S. EPA, 1986a)

Metals/Metalloids

- Atomic Absorption Spectrophotometry (AAS) USEPA Method 7000 series
  - flame
  - graphite furnace (GFAA)
  - cold vapor USEPA Method 7470
  - gaseous hydride (HYDAAS) USEPA Methods 7060 and 7740
- Inductively Coupled Plasma Emission Spectrometry (ICP) USEPA Method 6010

Organics

- Gas Chromatography (GC)
  - with electron capture detection (GC/ECD) USEPA Method 8080
  - with mass spectrometry (GC/MS) USEPA Methods 8240 and 8270

ICP – Al, Sb, As, Ba, Be, B, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Mo, Ni, K, Se, Sn, Ag, Na, Tl, V, and Zn
AAS – Al, Sb, As, Ba, Be, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Hg, Mo, Ni, K, Se, Ag, Na, Tl, Sn, V, and Zn

generally based on those described by Plumb (1981). Variations and improvements are being developed continuously and can be found in more recent publications. As an overall guide, it is recommended that the latest EPA method or equivalent acceptable method be used. Either USEPA regional laboratories, or other laboratories working within the USEPA Contract Laboratory Program are recommended to perform the required analyses for routine monitoring.

Dissolved Metals: Sample collection methods have been discussed in Section 4.1. Appropriate sample handling methods require that samples be frozen and kept at -20°C (USEPA, 1987). Although specific holding times have not been recommended by USEPA, a maximum of 6 months (8 days for mercury, ASTM, 1991) would be consistent with holding times for water samples. A summary table for holding times, container types, and preservation methods is given in Table 4-3.

Selection of analytical methods is based on a trade-off between full-scan analyses, which are economical but cannot provide sufficient sensitivity for some compounds, and alternate methods that are more sensitive for specific compounds but can require greater analytical costs.

For sample preparation, the USEPA Contract Laboratory Program (CLP) requires the use of $HNO_3.H_2O_2$ for metal digestion (USEPA, 1991c). Because dissolved metals are the focus of the monitoring, and not total metals, more complete digestion procedures are not required. A combination of atomic absorption spectrophotometry (AAS) and inductively coupled plasma (ICP) emission spectroscopy is proposed for the detection and quantification of trace metals.
Analyses for aluminum, chromium, copper, nickel, silver, and zinc will be conducted using ICP emission spectroscopy. Analyses for arsenic, cadmium, lead, and selenium will be conducted using graphite furnace atomic absorption spectrophotometry (GFAAS). Mercury will be analyzed using cold vapor AAS (USEPA, 1986a).

Acid Volatile Sulfides (AVS) concentration has been shown to be a useful tool for predicting bioavailability of metals in anoxic sediments. While the focus of sediment sampling is in the aerobic zone, AVS analyses are recommended to extend the assessment of sediment quality. Analysis of (AVS) is recommended to be conducted in accordance with draft EPA method (USEPA, 1991c) using GFAAS. Total Organic Carbon (TOC) will be measured using a Coulometer TOC analyzer. Both of these parameters are recommended to be used to normalize metallic and organic contaminants, respectively.

Semi-Volatile Organic Compounds: The isotope dilution technique, which requires spiking the sample with a mixture of stable isotope labeled analogs of the analytes, is proposed because reliable recovery corrections can be made for each analyte with a labeled analog or a chemically similar analog (USEPA, 1986a). Holding times, container types, and preservation methods for organic compounds can be found in Table 4-3.

Table 4-3. SAMPLING CONTAINERS, PRESERVATION REQUIREMENTS, AND HOLDING TIMES FOR SEDIMENT SAMPLES

Contaminant	Container[a]	Preservation	Holding Time
Metals			
Chromium VI	P, G	Cool, 4°C	40 hours
Mercury	P, G		8 days
Metals, except above	P, G		6 months
Organic Compounds			
Extractables (including phthalates, nitrosamines, organochlorine pesticides, PCBs, nitroaromatics, isophorone, polynuclear aromatic hydrocarbons, haloethers, chlorinated hydrocarbons and TCDD)	G, teflon-lined cap	Cool, 4°C	7 days (until extraction) 30 days (after extraction)
Extractables (phenols)	G, teflon-lined cap	Cool, 4°C	7 days (until extraction) 30 days (after extraction)
Purgeables (halocarbons and aromatics)	G, teflon-lined septum	Cool, 4°C	14 days
Purgeables (acrolein and acrylonitrile)	G, teflon-lined septum	Cool, 4°C	3 days
Pesticides	G, teflon-lined cap	Cool, 4°C	7 days (until extraction) 30 days (after extraction)
Chlorinated organic compounds	G, teflon-lined cap	Cool, 4°C	7 days (until extraction) 30 days (after extraction)

[a] Polyethylene (P) or Glass (G)
SOURCE: American Society for Testing and Materials, 1991

A combination of capillary gas chromatography with electron capture detection (CGC/ECD), gas chromatography with mass spectrometry (GC/MS), and compound-specific analyses is proposed for the detection and quantification of semi-volatile organic compounds (USEPA, 1986a). Analysis of pesticides will be conducted using CGC/ECD. CGC/ECD provides greater sensitivity relative to using GC/MS, however CGC/ECD does not provide positive compound identification. Confirmation of pesticides by GC/MS, when sufficient concentrations occur, is recommended. PCB congener-specific analyses are recommended because they provide more accurate identification and quantification of PCBs and eliminate the necessity of subjective decisions on the part of the analyst. Analysis of all other semi-volatile compounds will be conducted using GC/MS. These methods and the equivalent EPA Method numbers are summarized in Table 4-2.

Volatile Organic Compounds: Analyses of volatile organic compounds will be conducted using purge and trap CGC/ECD techniques (USEPA, 1986a). When sufficient concentrations occur, GC/MS is recommended. These methods and the equivalent EPA Method numbers are summarized in Table 4-2.

Detection Limits: Accurate measurement of bioavailable concentrations are required to evaluate hazards due to bioaccumulation of sediment contaminants. Over 80% of the available measurements of sediment organics are below detection limits. Selection of more sensitive state-of-the-art analytical methods should be considered for those parameters where there are toxicological data indicating the potential for effects at concentrations lower than obtained with routine methods. On the other hand, if there is no indication of adverse effects at present detection levels, there is no reason to reduce the detection limits.

Alternative Methods

AVS analyses, mentioned above, are recommended to be included in the routine suite of parameters to be monitored. Continuing developments in metal and organic analyses, especially in a saltwater matrix, should be tracked and considered for inclusion in the overall analytical program. This is especially true of methods that provide more robust analyses with lower detection limits.

4.4.3 QA/QC Considerations

Appropriate QA/QC procedures for collection and analysis can be found in several documents, including specific QA/QC guidance documents and also within the analytical methods documents. Each analytical laboratory should, as part of its overall QA/QC program, follow prescribed QA/QC procedures for each type of analysis performed. Some appropriate QA/QC references are:

> *Guidance for Sampling of and Analyzing for Organic Contaminants in Sediments.* U.S. Environmental Protection Agency, 1987. EPA 440/4-87-010.
>
> *Methods for the Determination of Metals in Environmental Samples.* U.S. Environmental Protection Agency, 1991. EPA 600-4-91-010.
>
> *Sampling and Analytical Methods of the National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984-1992.* NOAA, 1993. NOS ORCA 71.
>
> *EMAP-Estuaries Louisianian Province: Quality Assurance Project Plan for 1993.* U.S. Environmental Protection Agency (Heitmuller and Valente, 1993). EPA/600/X-93/XXX.

For analyses of metals, samples should be frozen and kept at -20°C (USEPA, 1987). Although specific holding times have not been recommended by USEPA, a maximum of 6 months (8 days for mercury; ASTM, 1991) would be consistent with holding times for water samples (Table 4-3).

For analyses of volatile compounds, samples should be stored in the dark at 4° C. Analyses of volatile compounds should be performed within 14 days of collection (USEPA, 1987). If analyses of semivolatile compounds will not be performed within the recommended 7-day holding time, freezing of the samples at -20° C is advised. Holding times for frozen samples has not been established by EPA (Table 4-3).

Samples for determination of TOC and AVS should be analyzed as soon as possible. If not analyzed immediately, TOC samples should be refrigerated and their pH brought below 2 by addition of phosphoric acid. Acidification is recommended only when inorganic carbon is below detection limits (APHA, 1992). AVS samples should be stored in airtight containers under an inert atmosphere and analyzed as soon as possible.

Field QA/QC Checks

Travel blanks can indicate whether contamination was introduced by reagents in the field or introduced during shipping of samples. Rinsate blanks are designed to verify the absence of contamination that can be carried over from one sample to another due to inadequate cleaning of field equipment. Field splits, treated and identified as separate samples, may be sent to the same laboratory for analysis or one sample may be sent to a "reference" laboratory for comparison. Standard reference material should be placed in a sample container at the time of collection and sent "blind" to the laboratory. Every 20th sample should be employed as a field blank.

Instrument QA/QC Checks

Calibration standards should be analyzed at the beginning of sample analysis, and should be verified at the end of each 12-hour shift during which analyses are performed (USEPA, 1987). The concentration of calibration standards should bracket the expected sample concentrations, otherwise sample dilutions or sample handling modifications (i.e., reduced sample size) will be required.

Method QA/QC Checks

Tables 4-4 and 4-5 provide a summary of sample/replicate/blank QA/QC procedures for laboratory analyses. Analysis of method blanks should be conducted to demonstrate the absence of contamination from sampling or sample handling in the laboratory. At least one method blank must be included with each batch of samples and should constitute at least five percent of all samples analyzed.

Table 4-4. SUMMARY OF QUALITY CONTROL SAMPLE

Sample Type	Recommended Frequency of Analysis
Surrogate spikes	Required in every sample - minimum 3 neutral, 2 acid spikes, plus 1 spike for pesticide/PCB analyses, and 3 spikes for volatiles. Isotope dilution techniques (i.e., with all available labeled surrogates) is recommended for full scan analyses and to enable recovery corrections to be applied to data.
Method blank	One per extraction batch (semivolatile organics). One per extraction or one per 12-hour shift, which ever is most frequent (volatile organics).
Standard reference materials	$<$50 samples: one per set of samples submitted to lab. $>$50 samples: one per 50 samples analyzed.
Matrix spikes	Not required if complete isotope dilution technique used. $<$20 samples: one per set of samples submitted to lab. $\geq$20 samples: 5 percent of total number of samples.
Spiked method blanks	As many as required to establish confidence in method before analysis of samples (i.e., when using a method for the first time or after any method modification).
Analytical replicates	$<$20 samples: one per set of samples submitted to lab $\geq$20 samples: one triplicate and additional duplicates for a minimum of 5 percent total replication.
Field replicates	At the discretion of the project coordinator.

Spike recovery analyses are recommended to assess method performance for the particular sample matrix. Spike recoveries serve as an indication of analytical accuracy, whereas analysis of standard reference materials (SRM) measure extraction efficiency. Recommended control limits include 75 to 125 percent recovery for spikes and 80 to 120 percent recovery for SRM.

Replicates are recommended to assess the precision of laboratory analyses. A minimum of five percent of the analyses should be laboratory replicates. The acceptable variation among replicates is 20 percent or less.

Table 4-5. SUMMARY OF WARNING AND CONTROL LIMITS FOR QUALITY CONTROL SAMPLE

Sample Type	Recommended Warning Limit	Recommended Control Limit
Surrogate Spikes	10 percent recovery	50 percent recovery
Method Blank Phthalate, Acetone	30 percent of the analyte of the analyte	5 µg total or 50 percent
Other Organic Compounds	1 µg total or 5 percent of the analyte of the	2.5 µg total or 5 percent of the analyte
Standard Reference Materials	95 percent confidence interval	95 percent confidence interval for Certified Reference Material
Matrix spikes	50-65 percent recovery	50 percent recovery
Spiked Method Blanks	50-65 percent recovery	50 percent recovery
Analytical Replicates	– coefficient of variation	±100 percent
Field Replicates	–	–
Ongoing Calibration		25 percent of initial calibration

4.5 SEDIMENT BIOASSAYS

Toxicity monitoring supports the evaluation of attaining the Resource Management Objective:

> WSQ-1: Eliminate ambient toxicity in Galveston Bay water and sediments by 2014.

The purpose of bioassay testing is to detect any adverse effect on aquatic organisms that might not otherwise be identified from direct chemical measurements or to correlate contaminant concentrations with acute or chronic observable biological effects. For example, bioassays are widely used in monitoring of permitted effluents to detect toxic effects that would not be shown in routine chemical monitoring.

4.5.1 Data Use and Limitations

Toxicity of bay sediments will be evaluated using sediment elutriate tests adopted from USEPA acute toxicity methods. Both a vertebrate and invertebrate species will be evaluated for responses to exposure to bay sediments. Marine tests are the 9-day embryo-larval and tetrogenicity chronic test for Inland Silversides *(Menidia beryllina)* and the 96-hour acute test for mysids *(Mysidopis bahia)*. These test species are included in the USEPA list of recommended acute toxicity test organisms (USEPA, 1991d). They are easily cultured in the laboratory, are sensitive to a variety of pollutants, and are generally available throughout the year from commercial sources. These tests, conducted by the USEPA Region 6 laboratory for the TNRCC, have been shown to provide valuable information on bay-area sediment quality.

Sediment elutriate testing, as opposed to whole sediment testing, was chosen because the Galveston Bay system is a shallow estuary in which the waters are frequently subject to moderate wind conditions, resulting in significant sediment resuspension. This method is used in support of the National Pollutant Discharge Elimination System permitting program within USEPA Region 6. It is planned that the method and test species will be evaluated over a two-year period to determine the value of the results. The procedures and test species are subject to modification after this time to improve the monitoring program and the assessment of progress toward the Resource Management Objective and associated action plans.

4.5.2 Sampling and Analytical Methods

Recommended Methods

The recommended method is identical to that developed by the USEPA Region 6 laboratory in Houston, and is adapted from USEPA (1988) and USEPA and USACE (1991). Sediment elutriates are prepared by combining a sub-sample from the homogenized sediment sample with the appropriate culture water ratio of 1:4 on a volume basis. After the correct ratio is achieved, the mixture is tumbled end-over-end for approximately 24 hours, after which time the mixture is allowed to settle for an additional 24 hours at 3-4°C. After settling, the supernatant is siphoned off without disturbing the settled material. If fine particulate matter is present and would prohibit the observation of the test organisms, the elutriate is then passed through a 1.5 micron glass fiber filter before testing is initiated.

Laboratory culturing, holding, and handling protocols for the test organisms are described in:

> *Methods for Measuring the Acute Toxicity of Effluents and Receiving Waters to Freshwater and Marine Organisms. 4th ed.* USEPA, 1991.

Laboratory procedures for acute toxicity testing and subsequent data analysis are also addressed in the same document.

Alternative Methods

Because these procedures and test species are under evaluation as to their utility for the Galveston Bay Regional Monitoring Program for the next two years, no changes are recommended. Once sufficient results from the bioassay testing have been accumulated, an analysis of those results may provide indications as to how the methods or species may be improved.

4.5.3 QA/QC Considerations

Quality assurance protocols applicable to facilities and equipment, test organisms, elutriate sampling and handling, and acceptability of acute toxicity test results are discussed in detail in the procedures document cited above (USEPA, 1988).

CHAPTER 5
HABITAT DISTRIBUTION AND CONDITION

Monitoring habitat distribution and condition in and around the Galveston Bay estuary will provide data necessary to directly or indirectly assess attainment of the following Resource Management Objectives:

- HP-3: Sustain no net loss of wetland areas.
- HP-4: Create or restore 15,000 acres of vegetated wetlands within 10 years.
- HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.

This Chapter is divided into two sections. Section 5.1 (Areal Extent, Distribution, and Classification) addresses methods that are used to monitor changes in the amount and distribution of habitats. Section 5.2 (Habitat Function and Value) describes methods that are used to evaluate the condition of habitats based on their suitability for serving various ecological functions and values assigned them.

The Habitat Protection Task Force identified freshwater marsh, emergent estuarine marsh, and submerged aquatic vegetation (SAV) as candidate indicators of habitat distribution and condition in Galveston Bay.

5.1 AREAL EXTENT, DISTRIBUTION, AND CLASSIFICATION

The Galveston Bay estuary is composed of a variety of habitat types which support a diverse group of plant and animal species. The continued health and productivity of the Estuary depends on maintaining these diverse, high-quality habitats. Ensuring the protection of habitats in the Galveston Bay estuary is a major concern of the Galveston Bay National Estuary Program.

5.1.1 Data Use and Limitations

Monitoring the areal extent and distribution of selected habitats provides information that directly supports a determination of whether the following Resource Management Objectives are being met:

HP-3: Sustain no net loss of wetland areas.
HP-4: Create or restore 15,000 acres of vegetated wetlands within 10 years.

The methods used to classify Galveston Bay habitats and monitor their areal extent must be capable of differentiating various wetland types and quantifying their extent with an acceptable level of accuracy. To ensure that valid comparisons can be made with existing data, the classification system used should also be comparable with previously identified wetland types in Galveston Bay and be consistent with that used in monitoring wetland function and value (Section 5.2). This will allow net changes in wetland function and value to be estimated on an estuary-wide basis.

Agency Mandates/Objectives

In 1991 the TNRCC defined wetlands and included them as waters of the state thus providing these areas protection under the Texas Surface Water Quality Standards (TNRCC, 1994). The TNRCC identifies six wetland categories in the Standards: Tidal Wetlands, Brackish Wetlands, Isolated Wetlands, Playa Lakes, Riparian Wetlands, and Forested Wetlands. The following revisions to the standards proposed in the 1994 triennial review (TNRCC, 1994) also are relevant to regional monitoring of wetland aerial extent and distribution:

- Site-specific assessment of uses and standards in response to any TNRCC permitting action

- Numerical criteria to protect aquatic life from acute toxicity and additional numerical toxic criteria where appropriate.

TNRCC (1994) states that the wetland standards are particularly pertinent to:

- State reviews of U.S. Army Corps of Engineers permits for dredge and fill operations

- Delegation and implementation of the Texas Coastal Zone Management Program.

5.1.2 Sampling and Analytical Methods

This subsection begins with a brief description of sampling and analytical methods that have been used to measure the areal extent and distribution of habitats in Galveston Bay. The Regional Monitoring Steering Committee has selected a monitoring approach from among these alternatives for use in the Galveston Bay Regional Monitoring Program.

Existing Monitoring Programs

The U.S. Fish and Wildlife Service (USFWS) National Wetlands Inventory (NWI) and the National Oceanic and Atmospheric Administration (NOAA) Coast Watch

Change Analysis Program (C-CAP) measure the extent and distribution of habitats in Galveston Bay. In addition, GBNEP has sponsored research directed at mapping the extent and distribution of various wetland types in Galveston Bay, based on NWI data. Although several investigators have measured the extent and distribution of SAV in Galveston Bay, there is no routine monitoring of this habitat in the estuary.

The USFWS NWI is establishing a database on the extent and characteristics of wetlands in the United States based on aerial photographs. Under this program wetlands are mapped on 7.5 - or 15 - minute U.S. Geological Survey topographic maps and classified according to the USFWS Classification of Wetlands and Deepwater Habitats of the United States (Cowardin, et al., 1979; USFWS, 1990). Photo interpretation, cartographic, and digitizing conventions have been adopted by the USFWS to ensure consistency and aid workers in photo interpretation and mapping (USFWS, 1990; USFWS, 1994a; USFWS, 1994b).

Eventually the entire USFWS NWI system will be computerized into digital geographic information systems (GIS) to provide continuous, detailed monitoring of the extent of wetlands described according to the Cowardin et al. (1979) system (Mitsch and Gosselink, 1993). Because NWI maps use the classification system of Cowardin et al. (1979), the wetland types to be monitored must be compatible with this system or additional photo interpretation will be required. The NWI is presently preparing status and trends reports for a number of regions in the United States, including coastal Texas (Warren Hagenbuck, personal communication).

National Wetland Inventory maps are suitable for determining the general location of various types of wetlands and for estimating large scale changes in the extent of wetlands. However, identifying specific boundaries will require site-specific measurements since even a fine line drawn on the 1:24,000 scale NWI maps represents approximately five meters (Mitsch and Gosselink, 1993). National Wetland Inventory maps have been used extensively during the EIS process to identify projects potentially impacting wetlands and to describe trends in the extent of wetlands in specific geographic regions (Dennis Peters, personal communication).

The NOAA C-CAP is developing standardized approaches to classifying and monitoring coastal habitats from satellite thematic mapping (TM) imagery (Pulich and Hinson, 1992). The classification system used by NOAA C-CAP includes Wetland, Open Water, and Upland classes that are further divided into a hierarchical system based on attributes such as water salinity, plant morphology, and landscape structure. Digital satellite imagery data covers larger areas and is available at relatively frequent intervals allowing comparisons to be made over shorter time periods than with aerial photography. Impacts due to catastrophic events as well as long term trends in the extent and distribution of habitats can therefore be evaluated.

The objectives of the GBNEP trends and status project were to: 1) identify specific Galveston Bay wetland plant communities associated with wetland signatures on aerial photographs, and 2) assess the status and trends of wetland and aquatic habitats in Galveston Bay based on mid-1950s, 1979, and 1989 photographs (White and Paine, 1992). Information obtained by the GBNEP sponsored efforts to evaluate wetland loses in the estuary since 1959 will establish a baseline estimate of wetland extent in the area. Surveys conducted in 1990 and 1991 (White and Paine, 1992) can be used to determine how well the Cowardin et al. (1979) system describes wetlands in Galveston Bay.

Pulich and White (1991) studied historic changes in the aerial extent of submerged vegetation in West Bay using aerial photography from 1956, 1965, 1975, and 1987. Other researchers (e.g., White et al., 1985) have also successfully mapped areas of submerged vegetation in Galveston Bay based on aerial photography (Pulich et al., 1991). Although the NWI is based on aerial photography, submerged vegetation has not consistently been identified on the NWI maps. Additional analyses could be conducted, however, following the USFWS photo interpretation, cartographic, and digitizing conventions (USFWS, 1990; USFWS, 1994a; USFWS, 1994b) using existing aerial photography.

Recommended Monitoring Approach

Pulich and Hinson (1992) used C-CAP methodologies to classify and inventory wetland habitats over an area of 170 km^2 in lower West Galveston Bay. White et al. (1993) used NWI maps to classify and inventory wetland and aquatic habitat areas throughout the Galveston Bay estuary. Results from each of these studies indicate that either method would be suitable for monitoring the extent and distribution of freshwater marsh and emergent estuarine marsh in Galveston Bay. Although it may be possible to measure the aerial extent of submerged vegetation using these methods, neither will provide suitable species composition data for this habitat type. It is strongly recommended that the distribution and abundance of individual submerged vegetation species be monitored.

Because of the ability to provide more frequent analysis, the Regional Monitoring Steering Committee selected the C-CAP methodologies for use in the Galveston Bay Regional Monitoring Program. Pulich and Hinson (1992) developed a set of classification methodologies based on C-CAP specifically for application along the upper Texas coast. These methodologies are recommended for all monitoring of habitat extent and distribution under the Galveston Bay Regional Monitoring Program. The classification system used by Pulich and Hinson (1992) includes nine Level 1 subclasses of wetland and upland habitat found in the Galveston Bay area (Table 5-1).

5.1.3 QA/QC Considerations

Hinson et al. (1994) provides an evaluation of two methods used for determining the accuracy of wetland and landcover classification based on TM imagery. Ground-truthing techniques demonstrated that accuracy exceeding 85% could be achieved for 10 major landcover classes using satellite TM imagery. Routine ground-truthing of satellite TM imagery mapping should be conducted to ensure that this level of accuracy is maintained during all habitat monitoring under the Regional Monitoring Program.

Table 5-1. CANDIDATE INDICATORS AND MEASUREMENTS FOR HABITAT PROTECTION

Indicator Habitats	Measurement
Marsh	
• All marsh types	Areal extent and distribution % emergent vegetation % open water dominated by aquatic vegetation Marsh edge and interspersion Water duration Open water depth Salinity\ Aquatic organism access
• Brackish marsh	Change in relative sea level-subsidence/erosion
• Salt marsh	Percent *Spartina alterniflora*
Submerged Vegetation • Sea grasses	Areal extent and distribution Biomass Vegetation spp composition PAR Salinity
Oyster reefs	Areal extent and distribution
Colonial waterbird nesting habitat	Number of colonies and distribution # nesting pairs Abundance of predators (e.g., raccoons) Elevation above sea level Connectivity to mainland Indications of human disturbance

White et al. (1993) identify seven species of submerged aquatic vegetation found in the Galveston Bay estuary. Two of these species, turtlegrass *(Thalassia testudinum)* and clovergrass *(Halophila engelmannii)*, are extremely limited in their distributions and may warrant special attention. Because the species composition of submerged aquatic vegetation cannot be determined from aerial photographs or TM imagery, extensive ground truthing will be necessary for this habitat type.

5.2 HABITAT FUNCTION AND VALUE

Function, particularly when referring to wetland habitats, represents the ecological benefits that a habitat provides. Wetland functions, for example, include fish and wildlife habitat, nursery areas, and food web support, among others. Habitat values are a measure of the human benefits that are provided by a habitat. Wetland values include flood control, shoreline protection, and recreational opportunities.

Quantifying habitat function and value allows managers to monitor trends in habitat quality that could not be measured by extent and distribution alone. Presently no agency monitors habitat function or value in Galveston Bay on a routine basis.

5.2.1 Data Use and Limitations

Monitoring the function and value of habitats in Galveston Bay provides information directly supporting a determination of whether the following Resource Management Objective is being met:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.

Agency Mandates/Objectives

The TNRCC is responsible for protecting the quality of the state's surface water and groundwater resources. To accomplish this the TNRCC develops water quality standards, and regulates point and nonpoint pollution sources. Monitoring data is used by the TNRCC to:

1. Describe existing water quality in streams, reservoirs, and bays

2. Monitor the impact of industrial, municipal, and agricultural point source discharges on water quality

3. Assess water quality impacts resulting from spill events

4. Assess long-term trends in water quality

5. Compare existing water quality and established water quality standards (waste load allocations, water quality standards)

6. Conduct activities and make management decisions pertaining to the Texas Water Code and Federal Clean Water Act (permits, waste load allocations, water quality standards, etc.) (Guillen, 1991).

Revisions made to the Texas Surface Water Quality Standards in 1991 provided a definition of wetlands and included them as waters of the state. In 1994, the TNRCC proposed six categories of wetlands and revisions to the standards applicable to wetlands that include:

1. Narrative criteria for aesthetic, radiological, toxic, nutrient, and salinity parameters

2. Numerical limitations for thermal elevations

3. Fecal coliform limits considered appropriate for contact recreation

4. Site-specific assessment of uses and standards in response to any TNRCC permitting action

5. A description of the antidegradation policy and procedures

6. Numerical criteria to protect aquatic life from acute toxicity and additional numerical toxic criteria where appropriate (TNRCC, 1994).

Existing surface water quality standards are intended to protect the chemical conditions of the water. However, future revisions to the standards that would address the protection of wetland vegetation and habitat are being considered (TNRCC, 1994). In addition to these changes, the TNRCC is in the process of developing biocriteria for state waters based on existing aquatic life subcategories. Biocriteria may require more quantitative measures of aquatic life attributes (e.g., habitat characteristics, species assemblages, and diversity) that are described for the aquatic life subcategories. Quantitative measures of habitat condition could be used in developing and applying biocriteria.

5.2.2 Sampling and Analytical Methods

Existing Assessment Techniques

A number of standardized techniques have been used for assessing habitat function and value including the Wetland Evaluation Technique (WET), Habitat Evaluation Procedure (HEP), and the Wetland Value Assessment Methodology and Community Models. In addition to these generalized procedures for habitat assessment, regionally specific methods have also been developed for some areas. The Chesapeake Bay Program, for example developed the Habitat Requirements for Chesapeake Bay Living Resources which establish habitat criteria for the protection of selected species in the Chesapeake Bay area.

The Wetland Evaluation Technique assesses the suitability of wetland habitat for 14 waterfowl species groups, 4 freshwater fish species groups, 120 species of wetland-dependent birds, 133 species of saltwater fish and invertebrates, and 90 species of freshwater fish. It does not, however, evaluate other important wildlife resources such as game and furbearing mammals (USEPA, 1992). Wetland functions and values are measured by characterizing the physical, chemical, and biological attributes and processes of the wetland (Adamus et al., 1987). Assessments based on WET also include consideration of a wetland's social significance, effectiveness (ability to perform a function), and opportunity to perform a function.

The Habitat Evaluation Procedure was developed by the USFWS for measuring the quality and quantity of habitat available for selected wildlife species. The relative value of a habitat is evaluated based on a comparison of either: 1) the value of different areas at the same point in time; and 2) the value of the same area at different points in time. By combining the two types of comparisons, the impacts on, or improvement in habitat quality as a result of proposed or anticipated land and water use changes on wildlife habitat can be quantified (Leonard and Clairain, 1986). The evaluation involves using the same key habitat components to compare existing habitat conditions and the optimum conditions for the species of interest (USFWS, 1980).

The Wetland Value Assessment (WVA) methodology was developed by the USFWS for use in prioritizing project proposals submitted for funding under the Coastal Wetlands Planning, Protection, and Restoration Act. This technique quantifies changes in wetland quality and quantity that are projected to be brought about as a result of a proposed project. The WVA is based on HEP, but rather than the species oriented approach of HEP, WVA utilizes a community based approach (USFWS, 1991). The WVA was developed specifically for application to the following coastal Louisiana wetland types: fresh marsh (including intermediate marsh), brackish marsh, saline marsh, and cypress-tupelo swamp (USFWS, 1991).

Recommended Monitoring Approach

All of the above described habitat assessment methodologies would require revisions to adapt them to the specific needs of GBNEP. Because WVA was developed for habitats similar to those found in the Galveston Bay estuary, this method has been selected for use in the Galveston Bay Regional Monitoring Program. Procedures for conducting habitat evaluations using WVA are described in Coastal Wetland Planning, Protection, and Restoration Act: Wetland Value Assessment Methodology and Community Models (USFWS, 1991).

The WVA operates under the assumption that optimal conditions for a coastal wetland can be characterized, and that any existing or predicted condition can be compared to that optimum to provide an index of wetland quality (USFWS, 1991). The quality component of a wetland is estimated or expressed through the use of a mathematical model developed specifically for each wetland type. Each model consists of 1) a list of variables that are considered important in characterizing the particular wetland type, 2) a Suitability Index graph for each variable, which defines the assumed relationship between wetland quality and the variable, and 3) a mathematical formula that combines the quality value (Suitability Index) for each variable into a single, overall value for wetland quality; that single value is referred to as the Habitat Suitability Index, or HSI. Use of WVA requires developing a list of variables characterizing the various wetland types found in Galveston Bay and a Suitability Index for each of those variables.

The Wetland Value Assessment models have been developed for determining the suitability of Louisiana coastal wetlands in performing or providing a diverse array of functions and values including, but not limited to: providing resting, foraging, breeding, and nursery habitat to a diverse assemblage of fish and wildlife species; providing storm-surge protection, flood water storage, and water quality functions; and serving in nutrient import/export. Those functions are loosely equated to wetland "quality" in that a wetland that provides or performs those functions and values better or to a greater degree than another may be considered to be of higher "quality" (USFWS, 1991).

5.2.3 QA/QC Considerations

Field testing will be required before the Wetland Value Assessment Methodology can be applied in the Galveston Bay area. Optimal conditions should be characterized for each of the selected indicator habitat types.

CHAPTER 6
SPECIES DISTRIBUTION AND CONDITION

Monitoring the distribution and abundance of selected species provides information to be used in assessing the following Resource Management Objectives:

- SP-1: At a minimum, maintain fish and crustacean population levels within 50% of 1975-1985 mean levels.
- SP-2: At a minimum, maintain oyster population levels within 50% of 1983-1993 levels.
- SP-3: Reduce bycatch within the estuary by 50% by the year 2007, accounting for seasonal patterns.
- SP-4: Reduce current levels of fish mortality caused by impingement/entrainment by 50% by the year 2007.
- SP-5: Increase populations of endangered and threatened species.
- SP-6: By the year 2005 reduce the abundance of selected exotic species, including nutria and grass carp, by 10%.

Information obtained from species population monitoring will also support assessments of four additional Resource Management Objectives:

- HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
- HP-6: Improve and protect habitat on 10 major colonial bird nesting sites within 5 years.
- WSQ-2: By the year 2004, ensure that all water quality segments within the estuary are in compliance with established dissolved oxygen standards.
- FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

For example, although species population data is not directly applicable to determining compliance with dissolved oxygen (DO) standards, such information will be needed to determine the applicable standard in some areas. The Texas Natural Resource Conservation Commission (TNRCC) is in the process of adopting DO standards based on aquatic life categories (TNRCC, 1994). Placement in an aquatic life category is based on a characterization of the community of organisms supported in a given waterbody. Results of species population monitoring could be used in assigning a waterbody to one of the aquatic life subcategories which will in turn determine what the appropriate DO standard is.

Chapter 6 is divided into 10 sections. Each addresses monitoring of a different community, species, or group of species. Sections 6.1 through 6.5 describe methods for monitoring various species that are recognized for their ecological importance. Sections 6.6 and 6.7 describe methods for monitoring commercially important finfish species and oysters, respectively. Section 6.8 describes the methods used in monitoring fisheries losses due to impingement and entrainment at water intake structures. Monitoring populations of introduced species is described in Section 6.9 and monitoring populations of threatened and endangered species is discussed in Section 6.10.

Specific indicator species have been selected for monitoring pelagic invertebrates (Section 6.2), finfish populations (Section 6.5), and finfish commercial harvest (Section 6.6). A list of these species is provided in each section. Finfish populations and finfish commercial harvest were separated because of the distinctly different methods used to monitor each of these groups and differences in the objectives for the two types of monitoring. However, for some species monitoring data are obtained through both programs. Three introduced species and four threatened or endangered species were selected for monitoring and methods are described separately for each.

6.1 PHYTOPLANKTON BIOMASS

Phytoplankton plays an important role as a primary producer in most estuarine ecosystems, including Galveston Bay. As such, changes in phytoplankton abundance often lead to corresponding changes in the abundance of phytoplankton consumers, particularly filter feeding zooplankton and benthic communities. Because of this relationship, information on phytoplankton biomass is often useful for interpreting changes in these other communities.

Phytoplankton communities are susceptible to a number of anthropogenic influences such as excess or deficient nutrient input and changes in salinity that could be associated with flow diversion. The relatively short life span and high growth potential characteristic of this group means that changes in environmental quality can lead to rapid changes in abundance and biomass. Because different species are favored under various environmental conditions (e.g., differences in salinity and nutrient availability) changes in community structure can provide an early indication of changing conditions in an area. Therefore measures of both community structure and biomass are useful for assessing ambient water quality conditions.

Phytoplankton biomass is most frequently estimated through the measurement of chlorophyll-*a* concentration. Chlorophyll-*a* typically constitutes approximately 1.5 percent of the dry weight of organic matter in phytoplankton and total biomass can be estimated by multiplying chlorophyll-*a* content by 67 (APHA, 1992). The ratio of chlorophyll-*a* to pheophytin-*a* (a degradation product of chlorophyll-*a*) is often used as an indicator of the physiological condition of phytoplankton.

6.1.1 Data Use and Limitations

Phytoplankton monitoring provides information indirectly supporting determinations of whether the following three Resource Management Objectives are being met:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
WSQ-2: By the year 2004, ensure that all water quality segments within the estuary are in compliance with established dissolved oxygen standards.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

For example, it is inappropriate to estimate annual and seasonal freshwater inflow needs (Objective FW-2) based solely on historic levels. Such an estimate should be based on the condition of various communities found in the estuary under different levels of inflow. Because the phytoplankton community responds quickly to changes in salinity, nutrient availability, or water temperature, this group would provide an excellent indicator of the effects that various levels of freshwater inflow have on the health of the estuary. Changes in the phytoplankton community can provide a similar indirect measure of wetland function and aid in determining the cause of low dissolved oxygen concentrations in a water quality segment. Information from the phytoplankton component of the Regional Monitoring Program can also be useful for selecting appropriate actions necessary to reach these objectives.

Agency Mandates/Objectives

The TNRCC is responsible for protecting the quality of the state's surface water and groundwater resources. To accomplish this the TNRCC develops water quality standards, and regulates point and nonpoint sources of pollution. Monitoring data are used by the TNRCC to:

1. Describe existing water quality in streams, reservoirs, and bays

2. Monitor the impact of industrial, municipal, and agricultural point source discharges on water quality

3. Assess water quality impacts resulting from spill events

4. Assess long-term trends in water quality

5. Compare existing water quality and established water quality standards (waste load allocations, water quality standards)

6. Conduct activities and make management decisions pertaining to the Texas Water Code and Federal Clean Water Act (permits, waste load allocations, water quality standards, etc.) (Guillen, 1991).

The TNRCC is primarily concerned with measuring the physical/chemical characteristics of water for comparison with state standards and criteria and permit limitations. Biological data, however, serve a number of purposes that include identifying appropriate designated uses, assessing water quality standards and criteria, and measuring the ecological impact of changes in water quality. In addition, the TNRCC is presently working to develop biocriteria based on quantitative biological indices used to define aquatic life categories (TNRCC, 1994). Phytoplankton condition and biomass are useful measures of environmental condition provided sufficient long-term data are available for analysis.

Phytoplankton monitoring provides important ancillary information necessary to properly interpret the results of other monitoring program components. It is important that this monitoring effort be coordinated with other program components and that the phytoplankton monitoring data be readily available. This is discussed in greater detail in Section 6.1.2 and in sections describing the methods for these other components of the Regional Monitoring Program (e.g., Section 5.2 Habitat Function and Value).

6.1.2 Sampling and Analytical Methods

This subsection begins with a brief description of monitoring or research programs that measure phytoplankton biomass in Galveston Bay. A monitoring approach has been selected from among these alternatives for use in the Galveston Bay Regional Monitoring Program. The selection was based on an evaluation of data comparability, costs, sensitivity, accuracy, precision, and robustness of the various methods.

Existing Monitoring Programs and Special Studies

Presently the TNRCC is the only agency conducting phytoplankton monitoring in Galveston Bay. Data collected under this program are stored in the Surface Water Quality Monitoring Data Base. The program presently measures chlorophyll-*a* and pheophytin-*a*, but in the past has also measured community structure through direct species counts. Chlorophyll-*a* and pheophytin-*a* are measured at 55 stations four times a year through spectrophotometric analysis of water samples. Community structure was assessed twice a year at 10 stations; however, because of staffing limitations this has not been performed for several years.

Buskey and Schmidt (1992) identify ten short-term studies of phytoplankton communities in Galveston Bay and provide a brief summary of these studies. The majority were conducted during the 1970s and there has been no phytoplankton research since 1985 . Armstrong and Hinson (1973) provides one of few studies describing species composition over a wide area of the Galveston Bay estuary. Other studies have been very limited in their spatial coverage and most were designed to investigate local conditions.

Recommended Monitoring Approach

Chlorophyll-*a* and pheophytin-*a* concentration should be used to monitor phytoplankton biomass for the Galveston Bay Regional Monitoring Program. The methods used by TNRCC are suitable for assessing attainment of the Resource Management Objectives described above and to meet the general objectives of the

Regional Monitoring Plan. Computerized data from this program are available for some stations in Galveston Bay from as far back as 1968 (Guillen, 1991) providing a suitable long-term data set for assessing trends. The TNRCC monitoring program follows procedures outlined in the *Draft Water Quality Procedures Manual* (TWC, 1993) and Method 10200 H from *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992).

Sample Collection and Handling

The collection and handling of phytoplankton samples for the Galveston Bay Regional Monitoring Program will be done in accordance with the methods used by TNRCC. Three separate collection techniques to obtain samples for analysis of community structure and biomass are described in the TWC (1993). Samples may be collected using either a plankton net or a Kemmerer or Van Dorn sample bottle. The appropriate collection technique is determined by plankton density and whether or not the sample is to be used for measuring nannoplankton (organisms < 40 microns in diameter) abundance.

Samples for analysis of chlorophyll-*a* concentration should be collected using a Kemmerer or Van Dorn sample bottle as described in the TWC (1993). However, no fixatives should be applied to the samples and they should be kept in the dark at 4° C to prevent the chlorophyll values from being altered during transport and storage.

Sample Analysis

Chlorophyll-*a* concentrations should be measured through spectrophotometric analysis of samples as described in *Standard Methods for the Examination of Water and Wastewater* (APHA, 1992).

Supporting Ancillary Information

The TNRCC program collects samples for the analysis of a suite of water quality and biological parameters at the same time that phytoplankton samples are collected. Water column variables that are measured as part of the TNRCC program, and should therefore be included in the Galveston Bay Regional Monitoring Program, are listed in Table 6-1. These ancillary data are important for properly interpreting changes in the phytoplankton community and for making comparisons with existing data. The methods to be used in measuring these other parameters are described in the *Draft Water Quality Monitoring Procedures Manual*

Table 6-1. PHYTOPLANKTON MONITORING PARAMETER LIST

Secchi Depth	Orthophosphate
pH	Nitrite-N
Water Temperature	Nitrate-N
Dissolved Oxygen	Ammonia-N
Salinity	Total Phosphorus
Biochemical Oxygen Demand	Pheophytin-*a*
Total Suspended Solids	Chlorophyll-*a*

Additional Considerations

It is recommended that phytoplankton community structure be measured periodically, particularly if significant changes in nutrient availability, zooplankton community structure, or benthic infauna community structure are detected. Such sampling should be done at all stations where phytoplankton biomass is measured in conjunction with that sampling. It is recommended that community structure be measured through the identification and counting of individuals as described in TWC (1993). A minimum of three subsamples should be drawn from each sample and analyzed in a 1-ml plankton chamber. Standard taxonomic references to be used in community descriptions are listed in the TWC (1993).

It is important to coordinate the phytoplankton monitoring program with measurements of the Bay's physical/chemical and biological characteristics. Phytoplankton communities in Galveston Bay show considerable seasonal and long-term variability and are characterized by a series of small blooms that occur throughout the year (Buskey and Schmidt, 1992). This variability may be influenced by any of a number of factors including light availability, nutrients, and water temperature. These factors are in turn influenced by a suite of other environmental factors. By coordinating sampling among the various Regional Monitoring Program components, the value of the data for making management decisions will be greatly enhanced.

Alternative Monitoring Approaches

Spectrophotometric measurement of chlorophyll-*a* provides a relatively fast, simple, and cost effective determination of the active photosynthetic pigments in phytoplankton. Although the method provides reproducible results, sensitivity and accuracy are effected by accessory pigments present at variable levels in different species of phytoplankton. Despite variability due to the presence of these accessory pigments, spectrophotometric determinations provide greater accuracy than alternatives such as cell counts, total cell volume estimates, protein estimates, and dry weight determinations.

Two alternative analytical techniques, fluorometry and high-performance liquid chromatography (HPLC), can be used to measure chlorophyll-*a* concentrations.

HPLC can also be used to obtain additional information about the major taxonomic groups in a sample based on the relative proportions of different pigments characteristic of the groups (Buskey and Schmidt, 1992).

Fluorometric Analysis: Submersible fluorometers enable *in situ* measurement of chlorophyll concentration, eliminating the need to transport samples back to the laboratory for analysis. Fluorometric techniques are also are more sensitive than spectrophotometry (APHA, 1992). The use of a submersible fluorometer will allow for faster data collection, integrated electronic storage of the data, simultaneous collection of associated water column data (such as, transmissivity, dissolved oxygen, depth, temperature, and conductivity), and, in most cases, lower cost. Submersible fluorometers are available from Sea Tech, Inc., Corvalis, OR at a cost of about $10,000.

Because both fluorometric and spectrophotometric methods measure chlorophyll-*a* concentrations, the resulting data are comparable. However, samples analyzed using different techniques should not be combined for statistical analysis. If the analytical technique is changed, it is recommended that samples be analyzed using both methods for at least one year.

Fluorometric analysis of chlorophyll-*a* as a measure of phytoplankton biomass provides the following advantages over spectrophotometric methods presently being used:

1. lower cost
2. *in situ* measurement
3. faster data collection
4. greater sensitivity.

These benefits should be balanced against the following disadvantages of changing to fluorometric analysis:

1. inability to statistically compare results with historic data
2. initial costs for new equipment and training
3. increased maintenance costs of field equipment.

High-Performance Liquid Chromatography (HPLC): A second alternative to spectrophotometric methods is to use HPLC analytical techniques. Although this method provides the most accurate measurement of chlorophyll, it is also the most expensive. With HPLC, measurements of phytoplankton pigments can be made to estimate the relative composition of major taxonomic groups in the samples (Buskey and Schmidt, 1992). This type of analysis can be performed more quickly, and therefore less expensively, than direct counts of species and individuals. Some of the additional cost may be offset if this provides a suitable estimate of community composition. Detailed information on per sample costs and specific statements of program objectives (i.e., what level of taxonomic change indicates a change in Galveston Bay) would be necessary to evaluate the cost advantages of using this HPLC method.

High-Performance Liquid Chromatography measurements of chlorophyll concentration provide the following advantages over the approach presently being used:

1. measurement of various pigments present in phytoplankton (allows determination of major species groups present in the sample)

2. a lower cost measure of community structure than direct species count methods.

These benefits must be balanced against a significantly higher overall cost for analysis.

6.1.3 QA/QC Considerations

Phytoplankton sampling conducted under the Galveston Bay Regional Monitoring Program will be subject to the Quality Assurance/Quality Control procedures outlined in the *Draft Water Quality Monitoring Procedures Manual* (TWC, 1993). The program includes annual quality assurance visits by the Water Quality Monitoring Unit, an annual Water Quality Monitoring Workshop, the collection of field and laboratory quality control samples, and data entry quality assurance checks. The TNRCC quality assurance program for laboratories analyzing water quality monitoring samples is described in a separate document.

Annual quality assurance visits will be conducted at any office participating in the Galveston Bay Regional Monitoring Program to ensure that personnel are using acceptable monitoring procedures and that these procedures are consistent with those selected by GBNEP.
Quality control is provided through the analysis of split and duplicate samples. Split samples, made by splitting the contents of a 2-1/2 gallon sample at the time of collection, are used to assess variability introduced during preservation, transport, and analysis. Field duplicates are samples collected sequentially at a station. Differences between these samples indicate the amount of variability due to field handling and transport procedures. One split sample and one duplicate sample are to be collected and analyzed for every 40 samples collected in the field. More specific procedures for collecting these samples and submitting them for analysis are contained in the *Draft Water Quality Monitoring Procedures Manual* (TWC, 1993).

Additional Considerations

A high level of natural variability is typically observed among phytoplankton samples. Variability in measurements due to field heterogeneity is quantitatively determined by the analysis of replicate field samples. Analysis of replicate samples is necessary for assessing the reliability of spatial and temporal comparisons. It is recommended that a minimum of three replicate samples be collected at each station (U.S. EPA, 1992).

Laboratory performance and calibration should be verified at the beginning and periodically (every 20 samples) during the time analyses are performed through the use of standards or blanks. Chlorophyll quality control samples can be obtained from the U.S. EPA Environmental Monitoring Support Laboratory in Cincinnati, Ohio. Standards can be used to evaluate performance without interference from natural variability. The *Interim Guidance on Quality Assurance/Quality Control (QA/QC) for Estuarine Field and Laboratory Methods* (U.S. EPA, 1985) provides a standard procedure for chlorophyll measurements.

6.2 INVERTEBRATE SPECIES

A diverse group of invertebrates are present in the Galveston Bay estuary. Many are important for their commercial/recreational value or their role as intermediate consumers in the ecosystem. The Species Population Protection Task Force of GBNEP has identified the following three species as indicators for this group:

- white shrimp *(Penaeus setiferus)*
- brown shrimp *(Penaeus aztecus)*
- blue crab *(Callinectes sapidus)*.

Many species of invertebrates are dependent on wetland habitats during a critical period of their life cycle (e.g., spawning, juvenile stages). Changes in the extent and quality of wetlands may therefore lead to changes in the abundance of many invertebrate species (particularly their juvenile stages). Members of this group frequently exhibit planktonic larval stages whose survival and dispersal can be strongly influenced by the magnitude and timing of freshwater inflow.

6.2.1 Data Use and Limitations

Monitoring invertebrate populations provides information directly supporting a determination of whether the following Resource Management Objective is being met:

SP-1: At a minimum, maintain fish and crustacean population levels within 50% of 1975-1985 mean levels.

Invertebrate data will also support determinations of whether the following Resource Management Objectives are being met:

SP-3: Reduce bycatch within the estuary by 50% by the year 2007, accounting for seasonal patterns.
SP-4: Reduce current levels of fish mortality caused by impingement/entrainment by 50% by the year 2007.
HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

For example, evaluating the impacts of bycatch or impingement/entrainment on populations must include consideration of changes in the abundance of the species being considered. Invertebrate data can also support assessments of wetland function because many of these species are dependent on wetland habitats for all or part of their life. Similarly, because many of these species are strongly influenced by changes in freshwater inflow, changes in their abundance can be used to determine annual and seasonal inflow needs.

Agency Mandates/Objectives

The Texas Parks and Wildlife Department (TPWD) monitors populations of selected invertebrates as part of its Resource Monitoring Program. The objectives of that program are:

- Develop long-term trend information on finfish and shellfish population abundance and stability

- Monitor environmental factors which may influences finfish and shellfish availability

- Determine growth, mortality and movement of selected species through recapture of tagged fish and by scale analysis.

The NMFS Baseline Production Program is administered by that agency's Galveston Laboratory. Research is conducted at the Galveston Laboratory to study relationships between various habitats in Galveston Bay and fisheries production. Ongoing projects address (Zimmerman et al., 1992):

- Measuring habitat utilization by selected fish and pelagic invertebrate species

- Identifying factors that affect juvenile abundance for selected fish and pelagic invertebrate species

- Creating salt marshes that benefit important fisheries species

- Developing an estuarine information and data inventory.

6.2.2 Sampling and Analytical Methods

This subsection begins with a brief description of sampling and analytical methods that have been used to measure the abundance and distribution of invertebrate species in Galveston Bay. A monitoring approach has been selected from among these alternatives for use in the Galveston Bay Regional Monitoring Program. The selection was based on an evaluation of data comparability, costs, sensitivity, accuracy, precision, and robustness of the various methods.

Existing Monitoring Programs

Presently the TPWD Resource Monitoring Program and the NMFS Baseline Production Program measure invertebrate populations in Galveston Bay. The TPWD Resource Monitoring Program collects 45 gill net, 20 trawl, and 20 bag seine samples in Galveston Bay monthly. Trawl and bag seine samples are collected monthly, gill net samples are collected semiannually. Sampling sites are randomly selected from a grid system. Data collected include species name, number of individuals, size, weight (occasionally), sex, and maturity. Osborn et al. (1992) provide a description of data collected by the Resource Monitoring Program and detailed statistical analyses for a large portion of this data.

The NMFS Baseline Production Program collects samples at various stations in West Bay marshes using drop traps. Sampling is conducted between March and July on a biweekly basis. Data collected includes the species name, number of individuals, and biomass of selected target species. In the future this program will be expanded to sample 30 stations located throughout Galveston Bay.

Recommended Monitoring Approach

The methods used by the TPWD Resource Monitoring Program are best suited for meeting the Resource Management/CCMP Objectives stated above. The Resource Monitoring Program provides the best long-term data available for assessing Species Population Objective, SP-1. Standardized methods have been used for gill net sampling since 1975, for bag seine sampling since 1977, and for otter trawl sampling since 1982 (Osborn et. al., 1992).

It is recommended that invertebrate sampling for the Galveston Bay Regional Monitoring Program be conducted in accordance with the methods used by TPWD's Resource Monitoring Program. Four alternative sampling techniques (18.3 m long bag seine, 60.9 m long beach seine, 182.9 m long gill net, or 6.1 m wide otter trawl) are available. Detailed descriptions of each gear type and its operation are contained in the *Marine Resources Monitoring Operations Manual* (TPWD, 1993a).

Sampling stations are selected randomly from a grid system to ensure an equal chance of sampling each section of shoreline and open bay water. The appropriate sampling technique is selected based on the time of year and location of the sampling station. Sampling periods and environmental conditions (e.g., water depth, amount of obstruction, etc.) under which each sampling technique is to be used are described in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a).

All organisms greater than 5 mm in length are to be identified to the species level and counted. If an organism can not be identified within two hours it is to be identified to the lowest possible taxonomic level and preserved for later identification to the species level. For bag seine and beach seine samples, 19 randomly selected individuals of each pelagic invertebrate species are to be measured. For gill net samples 19 randomly selected individuals of each pelagic invertebrate species from each mesh size are to be measured.

Information to be recorded at the beginning and completion of sampling are listed in Table 6-2. This ancillary information is necessary to properly interpret changes in the abundance and distribution of invertebrate species and ensures that valid comparisons are made when the data is evaluated.

Species abundance data is recorded on a Marine Resource Monitoring Data Sheet and ancillary information is recorded on a Marine Resource/Harvest Investigation Meteorological and Hydrological Data Sheet. Example copies of these data sheets are included in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a). Codes for identifying sampling grid locations, species, sex and age of individuals, and the collection method used are also contained in the *Operations Manual*.

Alternative Monitoring Approaches

Osborn et al. (1992) recommend stratifying gill net and bag seine sampling by location as a means of improving program results. Although this issue is related to sampling strategy rather

Table 6-2. INVERTEBRATE MONITORING PARAMETER LIST

Cloud Cover
Lighting Conditions (i.e., day, night, twilight)
Wind Speed and Direction
Barometric Pressure
Rainfall (y or n) and Fog (y or n)
Wave Height
Tide Condition (slack-high, slack-low, ebb, flood, spring, neap)
Shallow Water Depth (nearest 0.1 m)
Deep Water Depth (nearest 0.1 m)
Maximum Water Depth at Station (nearest 0.1 m)
Water Temperature (nearest 0.1° C)
Dissolved Oxygen (nearest 0.1 ppm)
Salinity (nearest 0.1%)
Turbidity (NTU)
Bottom Type (clay, silt, sand, shell, gravel, rock)

than sampling method, it is an important consideration for the Galveston Bay Regional Monitoring Program. By stratifying invertebrate sampling efforts, a certain level of comparability with other Regional Monitoring Program components could be ensured. Furthermore, by stratifying sampling efforts it may be possible to ensure that the data gathered is suitable for use by other agencies (e.g., TNRCC wetlands sampling) so that cost sharing is possible.

Future monitoring under the Regional Monitoring Program may require sampling inside vegetated wetland habitats to better assess wetland function. The methods used by the TPWD Resource Monitoring Program are suitable for meeting the above stated objectives, but would be difficult to apply in these areas. Two alternative sampling techniques, drop traps and flume nets, might be appropriate for future sampling of invertebrates in vegetated areas.

Drop traps have been successfully used to sample a variety of shallow water habitats including marshes, submerged aquatic vegetation, oyster reefs, and bare mud and sand bottoms (Zimmerman et al., 1992).

Kneib and Wagner (1994) used flume weirs to investigate the use of intertidal marshes by fish and invertebrates on Sapelo Island, Georgia. The system they used consisted of a series of wooden support posts defining a pentagon-shaped sampling area of 100 m^2 (Kneib and Wagner, 1994). Removable screen panels (1.2 mm square mesh) were inserted between the posts to enclose the sampling area and capture nekton in the marsh. Pits fitted with removable screen baskets were installed at the lower apex of the pentagon to capture nekton as they moved out of the enclosure during the ebbing tide. Marsh use during different tidal stages could be assessed by installing the panels at different tidal stages. Kneib (1991) provided details on flume weir construction and operation.

6.2.3 QA/QC Considerations

Population data collected using nets of any form is only comparable if net mesh size and fishing effort are standardized. Gill net, trawl, beach seine, and bag seine data are standardized by catch per unit effort based on the size of the area sampled and fishing time. It is also desirable to standardize sampling by tidal stage and time of day to the extent practicable as most estuarine invertebrate species demonstrate a great deal of tidal and diurnal movement that must be accounted for. Although noise introduced to the data due to these behavioral patterns can be accounted for, a much larger data set will be required to achieve the same level of accuracy in estimates.

Consistency in the taxonomic identification of invertebrates can best be achieved through initiating a regional taxonomic program and establishing a reference collection. Regional taxonomic workshops should be conducted on a regular basis (e.g., biennially) with all agencies participating in the Galveston Bay Regional Monitoring Program attending. The TPWD should be responsible for establishing a reference collection including, at a minimum, examples of all species included in their coding system.

The TPWD *Marine Resource Monitoring Operations Manual* describes protocols for data submission and editing that should be followed during all pelagic invertebrate sampling conducted as part of the Regional Monitoring Program. The *Operations Manual* also describes computer data field checks that provide additional quality assurance. Routine equipment checks should be conducted at the beginning and completion of each sampling effort.

6.3 BIRD POPULATIONS

The Galveston Bay estuary is home to a number of important bird species throughout the year. The area also provides important nesting and wintering habitat for a large number of migratory species. Birds fill a variety of roles in the trophic structure of an ecosystem and may, depending on the species, be primary consumers, secondary consumers, or top carnivores. Because of their diversity and the wide range of ecological roles filled by birds, monitoring of this group is essential to measuring the health of the estuary.

Three functional groups (shorebirds, migratory waterfowl, and colonial nesting waterbirds) have been identified for monitoring bird populations in the Galveston Bay area. Although species will be counted separately, similarities among the members of these groups make it reasonable to conduct surveys of their abundances simultaneously using the same techniques. The aerial extent and condition of colonial nesting waterbird habitat will also be monitored under the Regional Monitoring Program. This group has very specific nesting habitat requirements and typically will return to specific sites each year to nest. For this reason they are very susceptible to development and habitat loss.

6.3.1 Data Use and Limitations

Information on the abundance and distribution of bird populations and the extent and condition of colonial nesting waterbird habitat will be used to determine whether the following Resource Management Objective is being met:

SP-5: Increase populations of endangered and threatened species.

Results from this component of the Regional Monitoring Program will also support a determination of whether the following Resource Management Objectives are being met:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
HP-6: Improve and protect habitat on 10 major colonial bird nesting sites within 5 years.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

For example, measurement of wetland use by certain bird species can provide a measure of wetland function. Similarly, certain bird species use freshwater habitats for nesting and/or feeding and changes in their abundance could provide one measure for estimating freshwater inflow needs.

Agency Mandates/Objectives

The Texas Parks and Wildlife Department (TPWD), in conjunction with the U.S. Fish and Wildlife Service (U.S. FWS) and the Texas Colonial Waterbird Society (TCWS), conduct an annual survey of colonial nesting waterbirds along the Texas Coast. The Texas Colonial Waterbird Census (TCWC) is intended to provide:

1. Comparative data suitable for identifying specific areas that deserve more intensive study
2. An annual indicator of conditions at known nesting sites (Wagner and Lange, undated).

6.3.2 Sampling and Analytical Methods

Existing Monitoring Programs

Colonial Nesting Waterbirds: The Texas Colonial Waterbird Census (TCWC) provides the best existing monitoring information for the colonial nesting waterbird functional group. The TCWC has censused breeding pairs at colonial waterbird nesting sites within 15 km of the Texas coast since 1973. Surveys are conducted annually during a two-week period beginning the last week of May. Standardized procedures have consistently been followed during the censuses and established data forms have been used for recording results since 1986. Most surveys in the vicinity of Galveston Bay are ground counts made by two to four people viewing colonies on foot or from a boat. Aerial surveys have also been conducted at a number of sites (Slack et al., 1992).

Shorebirds: Until recently, the U.S. FWS, Clear Lake office, conducted irregular monthly surveys of shorebird feeding habitats in the vicinity of Bolivar Flats. This sampling, because it was conducted monthly, provides much more reliable estimates of population size than annual surveys (Slack et al., 1992).

Migratory Waterfowl: TPWD in conjunction with U.S.FWS, has conducted an annual Mid-winter Waterfowl Survey since 1973. This survey consists of one systematic census conducted along transects, and another less systematic census of counting birds at selected locations. These data provide information on waterfowl abundance by species and transect or location. Such information can be used as an index of changes in the relative abundance of species and to assess trends in use patterns within the Galveston Bay area.

Colonial Nesting Waterbird Habitat: Colonial nesting waterbirds utilize two general types of habitat for nesting. Ground nesting species prefer more open areas, often beaches or gravel bars. Tree and shrub nesting species prefer dense thickets of vegetation, often stands of emergent vegetation or large woody vegetation. Presently there is no monitoring of either habitat type in Galveston Bay.

Recommended Monitoring Approach

Colonial Nesting Waterbirds: It is recommended that colonial nesting waterbirds be monitored according to the TCWC protocols.

Shorebirds: It is recommended that shorebirds be monitored according to the protocols used in the shorebird surveys at Bolivar Flat. It is further recommended that sampling be reinstated at Bolivar Flat and that additional sites be selected for monitoring. These should include, but not be limited to, San Louis Pass and the Big Reef area.

Migratory Waterfowl: It is recommended that migratory waterfowl populations be monitored according to the protocols used in the annual Mid-winter Waterfowl Survey.

Colonial Nesting Waterbird Habitat: It is recommended that ten percent of the colonial nesting waterbird sites surveyed during the TCWC be selected for measuring the aerial extent and condition of both types of colonial waterbird nesting habitat (i.e., ground nesting and tree/shrub nesting sites). It is suggested that only sites which are at least 25-meter long and 10-meter wide be sampled and that sites be selected randomly each year. The recommended survey period is between the second Monday in February and the second Monday in March, prior to the start of the nesting season.

Measuring aerial extent and establishing transects: The first task at each site will be defining site boundaries and measuring the aerial extent of the site. It is recommended that boundaries be defined by evidence of the previous year's use (e.g., old nests). After boundaries are established, transects perpendicular to the long axis of the site can be marked by stakes placed at 5-meter intervals along opposite boundaries. It is recommended that the transects to be sampled are selected at random from among all available transects such that 10 percent of the transects are sampled, with no fewer than 5 total. It is also recommended that at least two stations be sampled along each transect. These stations can be selected at random along the length of the transect. It is suggested that ground cover measurements be based on 0.5-meter square plots placed at the centerpoint of each station.

Table 6-3 provides an initial list of suggested parameters to measure at each site. This initial list may be modified by the Species Population Protection Task Force as additional information indicating other important variables becomes available. Height above high tide line should be determined by measuring the vertical distance between the base of the nesting site and the upper limit of the debris line.

Table 6-3. COLONIAL NESTING WATERBIRD HABITAT PARAMETER LIST

Ground Nesting:

- Percent cover
- Predominant plant species present (>10 %)
- Substrate type (sand, gravel, etc.)
- Height above high tide line
- Distance from water

Tree/Shrub Nesting:

- Percent cover
- Predominant plant species present (>10 %)
- Diameter breast high (large woody vegetation only)
- Substrate type (sand, gravel, etc.)
- Height above high tide line
- Distance from water

In addition to the parameters listed in Table 6-3, any potential nest predators or signs of nest predators observed during the survey should be noted. This includes fire ants or fire ant nests found in the area. If fire ants are numerous an estimate of their density should be made. Fire ant colonies should be identified and their location in the nesting area described on a map of the area.

Additional Considerations

Slack et al. (1992) found data from the TCWC to be suitable for trend analysis of species regularly encountered during the surveys. They note, however, that the program does not provide a measure of observer effort. Future monitoring conducted as part of the Regional Monitoring Program should include measures of the time and area censused by observers.

As more species specific information on colonial nesting waterbirds becomes available it may be desirable to stratify sampling by species and focus efforts on selected species (e.g., listed threatened or endangered species). A list of habitat requirements for these species could be developed based on available literature and used to identify additional parameters to be measured and to help prioritize sampling.

6.3.3 QA/QC Considerations

It is recommended that anyone participating in bird surveys as part of the Regional Monitoring Program participate in taxonomic identification workshops prior to surveys. These workshops could provide instruction in call identification as appropriate. It is also recommended that workshops describing colonial nesting waterbird habitat sampling be conducted to familiarize participants with techniques used to measure the selected parameters, identify key plant and animal species, and record data.

6.4 ALLIGATOR POPULATIONS

The American alligator (*Alligator mississippiensis*) is a large, wetland dependent, commercially important, vertebrate predator. As such, alligator populations are very much influenced by a variety of human activities including development of wetlands, pollution, and over hunting. Large predators, feeding at higher trophic levels, are also more susceptible to the impacts of biomagnifying pollutants that might be present in the environment. Because changes in the abundance and distribution of alligator populations reflect habitat condition and a number of anthropogenic impacts, this species was selected as an indicator species in the Galveston Bay Monitoring Plan.

6.4.1 Data Use and Limitations

Information obtained from monitoring alligator populations will support an assessment of the following Resource Management Objective:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.

Agency Mandates/Objectives

The Texas Parks and Wildlife Department is responsible for regulating the annual alligator harvest in Texas. This requires information on the present status of alligator populations and their recruitment rates.

6.4.2 Sampling and Analytical Methods

The TPWD conducts night count surveys of alligators and helicopter surveys of alligator nests along the Texas coast. Established transects are located in the marshes adjacent to East Bay and Trinity Bay (Slack et al., 1992). Surveys were conducted annually from 1980 to 1984 and triennially since 1985. Night counts are conducted by two observers using spotlights to locate individuals from a boat. Nest counts are made along 91 m wide transects of variable length from an altitude of 91 m. Transects are spaced at 1.6 km or 4.8 km intervals. Surveys are conducted in May when vegetative growth in the marshes is low. During night counts efforts are made to standardize lighting equipment.

Recommended Monitoring Approach

The TPWD nest count and night count survey methods are suitable for monitoring changes in alligator populations in the Galveston Bay estuary. However, greater standardization of transect locations and sampling effort during nest counts would provide more meaningful data for little additional cost. The number and location of transects surveyed during nest counts was not consistent preventing direct temporal comparisons of the transects (Slack et al., 1992). Reducing the frequency of sampling from annual to triennial (due to funding limitations) limits the ability of the monitoring program to rapidly detect changes in alligator populations.

The following procedures for nest count surveys of alligator populations conducted as part of the Regional Monitoring Program are required:

- Sampling Locations - detailed description (include maps) of transect locations

- Transect Specifications - transects are 91 m in width. Lengths vary in accordance with habitat extent

- Flight Procedures - altitude is 91 m. Speed and minimum acceptable visibility are to be specified

- Survey Procedures - a detailed description of how nests are identified (i.e., presence of alligators, minimum size of depression, etc.), number of surveyors on plane, responsibilities of surveyors, record keeping procedures are to be specified.

For night alligator count surveys, these parameters and procedures must be established:

- Sampling Locations - detailed description (include maps) of transect locations
- Transect Specifications - description of the length and width of transects
- Boat Operation - boat speed, navigational method, distance and water depth
- Survey Procedures - lighting (power, number of lamps), number of surveyors, responsibilities of surveyors, record keeping procedures are to be specified.

All individuals or nests observed within the defined transect area are counted. The size of individuals should be estimated to the nearest 0.5 m during night counts. Any distinguishing characteristics are to be noted. The condition of individuals should be recorded when alligators show evidence of disease or physical damage. The information listed in Table 6-4 should be recorded on the standard Alligator Night Count data sheet for each individual observed.

Table 6-4. ALLIGATOR MONITORING PARAMETER LIST
Air Temperature*
Water Temperature
Location
Predominant Vegetation
Activity (resting, hunting, feeding, etc.)

*Taken only at beginning and completion of sampling.

Additional Considerations

Conducting multiple surveys during each sampling year is recommended as a way to increase the ability of the program to detect meaningful changes in alligator populations (Slack et al., 1992).

6.4.3 QA/QC Considerations

Population estimates based on direct observations in the field are subject to a great deal of variability associated with differences among samplers and environmental conditions at the time of sampling (i.e., weather/visibility). At least two surveyors, each making independent counts, should be present during every survey. Sampling protocols (e.g., transect width and length, boat speed) should be strictly adhered to.

6.5 FINFISH POPULATIONS

Monitoring fish community structure provides *in situ* measures of the estuarine habitat and provides a powerful tool for evaluating spatial and temporal effects of anthropogenic and natural disturbances. Fish community data can be used to assess the effectiveness of pollution abatement programs and monitor long-term trends in environmental quality. Information about the population characteristics of finfish species is needed to evaluate regulations and management programs.

The Species Population Protection Task Force of GBNEP identified the following three fish species to be monitored as indicators for this group:

- bay anchovy *(Anchoa mitchilli)*
- Atlantic croaker *(Micropogonias undulatus)*
- gulf menhaden *(Brevoortia patronus)*

6.5.1 Data Use and Limitations

Finfish population monitoring provides information directly supporting a determination of whether the following Resource Management Objective is being met:

SP-1: At a minimum, maintain fish and crustacean populations within 50% of 1975-85 mean levels.

Meeting this objective will require monitoring data of sufficient precision to detect changes of the indicated magnitude (i.e., 50 percent) and a comparable estimate of historic (1975-85) population size. Data must therefore be collected using methods that are comparable with historic data.

Finfish population monitoring also provides information supporting determinations of whether the following Resource Management Objectives are being met:

HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

Agency Mandates/Objectives

The TPWD monitors finfish populations as part of its Resource Monitoring Program. The objectives of that program are:

- Develop long-term trend information on finfish and shellfish population abundance and stability

- Monitor environmental factors which may influence finfish and shellfish availability

- Determine growth, mortality and movement of selected species through recapture of tagged fish and by scale analysis (McEachron, 1991).

The TNRCC is responsible for protecting the quality of the state's surface water and groundwater resources. To accomplish this TNRCC develops water quality standards, and regulates point and nonpoint pollution sources.

The TNRCC is primarily concerned with measuring the physical/chemical characteristics of water for comparison with state standards and criteria and permit limitations. Biological data, however, serve a number of purposes that include identifying appropriate designated uses, assessing water quality standards and criteria, and measuring the ecological impact of changes in water quality. In addition, the TNRCC is presently working to develop biocriteria based on quantitative biological indices used to define aquatic life categories (TNRCC, 1994). Changes in finfish populations provide a useful measure of environmental condition.

The USEPA Environmental Monitoring and Assessment Program (EMAP) was developed to periodically assess and document the condition of the Nation's ecological resources with a regional scope appropriate to large-scale environmental problems. The goals of EMAP are to:

- Estimate the current status, trends, and changes in selected existing and newly-developed indicators of the condition of the Nations ecological resources

- Estimate the distribution and extent of the Nation's ecological resources

- Identify associations between selected indicators of natural and anthropogenic stresses and indicators of the condition of ecological resources (Tetra Tech, 1994).

The NMFS Baseline Production Program is administered by that agency's Galveston Laboratory. Research is conducted at the Galveston Laboratory to study relationships between various habitats in Galveston Bay and fisheries production. Ongoing projects address:

- Measuring habitat utilization by selected fish and invertebrate species

- Identifying factors that affect juvenile abundance for selected fish and pelagic invertebrate species

- Creating salt marshes that benefit important fisheries species

- Developing an estuarine information and data inventory (Zimmerman et al., 1992).

6.5.2 Sampling and Analytical Methods

Existing Monitoring Programs

The TPWD Resource Monitoring Program collects 45 gill net, 20 trawl, and 20 bag seine samples in Galveston Bay monthly. Trawl and bag seine samples are collected monthly, gill net samples are collected semiannually. Sampling sites are randomly selected from a grid system. Data collected include species name, number of individuals, size, weight (occasionally), sex, and maturity. Large live fish are tagged and released for growth and mortality estimates (Tetra Tech, 1994). Osborn et al. (1992) provide an analysis of results from the Resource Monitoring Program including detailed statistical analyses for a large portion of the data.

The TNRCC nekton sampling program samples 10 stations twice each year and three additional stations annually. A variety of methods are used to collect samples including: fishing rod, trotline, throwline, or handline; twenty-foot minnow seine (1/4 inch mesh); gill net; fish traps; trawl; cast net; water intake screens; backpack electrofisher; and boat mounted electrofisher. Data collected include identification of species and number of individuals. Samples may be retained for later identification or analysis of tissue contaminant concentrations.

The NMFS Baseline Production Program collects samples at various stations in West Bay marshes using drop traps. Sampling is conducted between March and July on a biweekly basis. Data collected include species name, number of individuals, and biomass of selected target species. In the future this program will expand to sample 30 stations located throughout Galveston Bay.

Recommended Monitoring Approach

The TPWD Resource Monitoring Program provides the most complete data set describing fish community and population characteristics for the Galveston Bay estuary. Gill net samples have been collected in the estuary since 1975, bag seines since 1977 and otter trawl samples since 1982. The methods used in TPWD's Resource Monitoring Program should be followed during all fish community and population monitoring conducted as part of the Galveston Bay Regional Monitoring Program. These methods are described in detail in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a).

Sample Collection and Handling

Sampling conducted to monitor changes in the abundance and distribution of finfish populations for the Galveston Bay Regional Monitoring Program should be done in accordance with the methods of TPWD's Resource Monitoring Program. Four alternative sampling techniques (18.3 m long bag seine, 60.9 m long beach seine, 182.9 m long gill net, or 6.1 m wide otter trawl) are available. Detailed descriptions of each gear type and its operation are contained in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a).

Sampling stations are selected randomly from a grid system to ensure an equal chance of sampling each section of shoreline and open bay water. The appropriate sampling technique is selected based on the time of year and location of the sampling station. Sampling periods and environmental conditions (e.g., water depth, amount of obstruction, etc.) under which each sampling technique is used are described in TPWD (1993a).

Sample Analysis

All organisms greater than 5 mm in length should be identified to the species level and counted. If an organism can not be identified within two hours it should be identified to the lowest possible taxonomic level and preserved for later identification to the species level. For bag seine and beach seine samples 19 randomly selected individuals of each fish species should be measured. For gill net samples 19 randomly selected individuals of each fish species from each mesh size should be measured. Special processing procedures are described for tarpon, snook, striped and hybrid bass, and grass carp in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a).

Supporting Ancillary Information

Information to be collected at the beginning and completion of sampling are listed in Table 6-5. This ancillary information is necessary to properly interpret changes in the abundance and distribution of fish species and ensures that valid comparisons are made when the data is evaluated.

Table 6-5. FISH COMMUNITY MONITORING PARAMETER LIST

Cloud Cover
Lighting Conditions (i.e., day, night, twilight)
Wind Speed and Direction
Barometric Pressure
Rainfall (y or n) and Fog (y or n)
Wave Height
Tide Condition (slack, ebb, flood)
Shallow Water Depth (nearest 0.1 m)
Deep Water Depth (nearest 0.1 m)
Maximum Water Depth at Station (nearest 0.1 m)
Water Temperature (nearest 0.1° C)
Dissolved Oxygen (nearest 0.1 ppm)
Salinity (nearest 0.1%)
Turbidity (NTU)
Bottom Type (clay, silt, sand, shell, gravel, rock)

Data Reporting

Species abundance data are recorded on Marine Resource Monitoring Data Sheets and ancillary information is recorded on Marine Resource/Harvest Investigation Meteorological and Hydrological Data Sheets. Example copies of these data sheets are included in TPWD (1993a). Codes for identifying sampling grid locations, species, sex and age of individuals, and the collection method used are also contained in the *Operations Manual.*

Alternative Monitoring Approaches

Osborn et al. (1992) recommend stratifying gill net and bag seine sampling by location as a means of improving program results. Although this issue is related to sampling strategy rather than sampling method, it is an important consideration for applying these methods to the Galveston Bay Regional Monitoring Program. By stratifying fish sampling efforts, a certain level of comparability with other Regional Monitoring Program components could be ensured. Furthermore, by stratifying sampling efforts it is possible to ensure that data are suitable for use by other agencies (e.g., TNRCC wetlands sampling) so that cost sharing is possible.
Future monitoring under the Regional Monitoring Program may require sampling inside vegetated wetland habitats to better assess wetland function. The methods used by the TPWD Resource Monitoring Program are suitable for assessing the above stated objectives, but would be difficult to apply in these areas. Two alternative sampling techniques, drop traps and flume nets, might be appropriate for future sampling of fish in these areas.

Drop traps have been successfully used to sample a variety of shallow water habitats including marshes, submerged aquatic vegetation, oyster reefs, and bare mud and sand bottoms (Zimmerman et al., 1992). Existing data for Galveston Bay is available through the NMFS Baseline Production Program.

Kneib and Wagner (1994) used flume weirs to investigate the use of intertidal marshes by fish and invertebrates on Sapelo Island, Georgia. The system they used consisted of a series of wooden support posts defining a pentagon-shaped sampling area of 100 m^2 (Kneib and Wagner, 1994). Removable screen panels (1.2 mm square mesh) were inserted between the posts to enclose the sampling area and capture nekton in the marsh. Pits fitted with removable screen baskets were installed at the lower apex of the pentagon to capture nekton as they moved out of the enclosure during the ebbing tide. Nekton were collected from the baskets after the tide receded from the marsh surface. Marsh use during different tidal stages could be assessed by installing the panels at different tidal stages. Kneib (1991) provided details on flume weir construction and operation.

6.5.3 QA/QC Considerations

Population data collected using nets of any form is only comparable if net mesh size and fishing effort are standardized. Gill net, trawl, beach seine, and bag seine data are standardized by catch per unit effort based on the size of the area sampled and fishing time. It is also desirable to standardize sampling by tidal stage and time of day to the extent practicable as most estuarine fish species demonstrate a great deal of tidal and diurnal movement that must be accounted for. Although noise introduced to the data due to these behavioral patterns can be accounted for, a much larger data set will be required to achieve the same level of accuracy in estimates.

Additional Considerations

Consistency in the taxonomic identification of fish can best be achieved through initiating a regional taxonomic program and establishing a reference collection. Regional taxonomic workshops should be conducted on a regular basis (e.g., biennially) with all agencies participating in the Galveston Bay Regional Monitoring Program attending. The TPWD should be responsible for establishing a reference collection including, at a minimum, examples of all species included in their coding system.

The TPWD *Marine Resource Monitoring Operations Manual* describes protocols for data submission and editing that should be followed during all fish sampling conducted as part of the Regional Monitoring Program. The Operations Manual also describes computer data field checks that provide additional quality assurance. Routine equipment checks should be conducted at the beginning and completion of each sampling effort.

6.6 FINFISH COMMERCIAL HARVEST

Although not directly related to any of the Resource Management Objectives, information on the commercial and recreational value of fish and shellfish harvested from Galveston Bay is important for a number of reasons. First it provides the primary means for assessing the economic value of fisheries. Such assessments are important for measuring the costs and benefits of human activities that impact the fisheries. Second, this information allows regulators to evaluate the effect of management actions (e.g., changes in regulations) on the resource. Three species are identified by the Species Population Protection Task Force as indicators of the condition of fish populations in Galveston Bay and whose commercial and recreational harvest should be monitored under the Regional Monitoring Program. These three species are:

- bay anchovy *(Anchoa mitchilli)*
- Atlantic croaker *(Micropogonias undulatus)*
- gulf menhaden *(Brevoortia patronus)*

Bycatch includes all non-target species kept or discarded by fisherman and target species that are discarded. The amount of bycatch taken in Galveston Bay is another concern related to commercial and recreational fisheries and specific management objectives related to bycatch have been identified. Because there are extensive commercial and bait shrimp trawl fisheries operating in Galveston Bay the potential to impact a number of important fisheries exists. In the following discussion, methods are described for monitoring commercial harvests, recreational harvests, and the types and quantities of species taken in the bycatch of commercial and bait shrimp trawlers.

6.6.1 Data Use and Limitations

Monitoring the species and numbers of finfish taken in the bycatch of commercial and bait shrimp trawlers will provide information directly supporting a determination of whether the following Resource Management Objective is being met:

SP-3: Reduce bycatch within the estuary by 50% by the year 2007, accounting for seasonal patterns.

Monitoring commercial and recreational finfish harvests will provide information supporting determinations of whether the following Resource Management Objectives are being met:

SP-1: At a minimum, maintain fish and crustacean populations within 50% of 1975-85 mean levels.
HP-5: Restore natural function and values to 50% of degraded wetlands within 20 years.
FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

The commercial harvest of finfish in Galveston Bay has been monitored since 1880 providing one of the most long-term data sets describing Bay fisheries available (Osborn et al., 1992). Although inconsistencies in data collection techniques prevent its use for statistical analyses of trends or changes in populations, it does provide valuable information about historical changes in community structure (i.e., the relative abundance of species).

Agency Mandates/Objectives

The TPWD, in conjunction with the National Marine Fisheries Service, monitors the commercial harvest of finfish in Galveston Bay. The objectives of the TPWD program are:

- Determine the live weight and ex-vessel value of finfish, crabs, oysters, shrimp, and other marine life purchased by seafood dealers from commercial fishermen as an indication of harvest (fishing mortality) by commercial fishermen to comply with Texas Parks and Wildlife Department (TPWD) Code (1985-86), Sections 61.051, 66.209, 66.217, 77.004, and 77.005

- Publish results in report form which will assist managers and legislators in effectively managing the coastal fisheries of Texas (TPWD, 1989).

The TPWD Texas Marine Sport Harvest Monitoring Program collects information on recreational fishing throughout Texas. The objectives of that program are:

- Determine estimates of total daylight marine resource landings, catch per unit of effort, and size composition by species for:
  - Bay and Gulf private-boat sport fishermen
  - Bay and Gulf party-boat (10 people or fewer) sport fishermen.

- Publish results in report form which will assist ecosystem and fishery managers in effectively regulating harvest (TPWD, 1993b).

6.6.2 Sampling and Analytical Methods

Existing Monitoring Programs/Special Studies

The TPWD Coastal Resource Harvest Commercial Landings Program monitors commercially harvested finfish, shrimp, crab, oyster, and other marine resources. Licensed seafood dealers are required to report information about all edible saltwater products purchased from commercial fishermen in Monthly Marine Products Reports submitted to TPWD or the National Marine Fisheries Service (NMFS). Data collected includes total weight or number of individuals, price per pound, and the name of the water body where the seafood was collected. Data from this program are stored on magnetic tape in a mainframe computer located in Austin.

The TPWD Coastal Resource Harvest Recreational Landings Program monitors recreational finfish harvests in Galveston Bay. Under this program on-site, trip-end interviews are conducted at 125 boat access survey sites. A total of 133 surveys are conducted each year. Data collected include specifics about the fishing effort of each boat interviewed, the number and species of fish landed, total length of fish landed, species sought, and fishing method.

Galveston Bay National Estuary Program sponsored work by NMFS to characterize bycatch associated with trawl shrimp fisheries in Galveston Bay. To accomplish this NMFS reviewed existing bycatch studies from Galveston Bay and conducted new sampling efforts to characterize the species composition and abundance of bycatch taken throughout the Bay. Historical information was found to be quite limited, consisting of several studies conducted during the 1980s. Furthermore, these studies were limited in their spatial and temporal coverage and frequently focused on a single species or small group of selected species. Martinez et al. (1993) describe three of the most prominent studies and discuss their results.

Twenty-five shrimp vessels (both commercial and bait trawlers) were selected by NMFS to participate in a study of bycatch in Galveston Bay. Nineteen of these 25 were randomly selected to provide samples from their operations for analysis of bycatch. Samples were collected by on-board observers during normal fishing operations and captains were paid up to $200 per sampling trip (Martinez, et al., 1993). Sampling was stratified by dividing the Bay into three fishing zones, Trinity Bay, Upper Galveston and East Bays, and Lower Galveston and West Bays.

Recommended Monitoring Approach

The methods used in the TPWD Coastal Resource Harvest Commercial Landings Program and Coastal Resource Harvest Recreational Landings Program are suitable for monitoring commercial and recreational finfish harvests, respectively. Data from past monitoring conducted under these programs provide valuable historic information that can be used to assess trends in commercial and recreational harvests. These methods should be applied during all commercial or recreational finfish harvest monitoring conducted as part of the Regional Monitoring Program.

Methods for monitoring bycatch in the commercial and bait shrimp trawl industry are described in Martinez et al. (1993). These methods are based on the work conducted by NMFS but may be modified to provide a more complete sampling of all commercial and bait shrimp vessels.

Commercial Harvest

Any individual applying for or renewing a seafood dealers license must indicate whether or not saltwater products will be purchased from commercial fishermen. A list of all license holders is maintained by TPWD. All licensed seafood dealers are to submit a Monthly Marine Products Report (MMPR) to TPWD. The MMPR covers the preceding month's transactions including total weight (or total number of individuals), price per pound, and the name of the water body where the catch was taken. Shrimp landings may either be reported directly to NMFS or by submitting a MMPR to TPWD. Details on the Coastal Resource Harvest Commercial Landings Program methods are contained in the *Commercial Harvest Field Operations Manual* (TPWD, 1989).

Recreational Harvest

The TPWD Coastal Resource Harvest Recreational Landings Program surveys the catch of sport-boat fishing landings throughout Texas. Estimates of fishing pressure are obtained through counts of trailers and empty wet slips at boat access sites. Survey sites are selected randomly but selection is weighted according to mean rove counts, adjusted for trailer location, percent bay and pass pressure, and percent angling parties. Landing rates and size composition of the catch by species are obtained through on-site interviews of boaters completing their trips.

Bycatch

TPWD has recently begun a bycatch monitoring program based on the work by NMFS. It is recommended that bycatch monitoring conducted as part of the Regional Monitoring Program follow the protocols developed for the TPWD monitoring program. The TPWD protocols call for collecting a sample of approximately 25 pounds (4 gallons of sample weighed to the nearest pound) after the total weight of the catch from a commercial shrimp trawl drag is obtained (TPWD, 1994). Samples are only collected from licensed commercial bay shrimp vessels. Samples are returned to a TPWD field station to obtain information on species composition, size, number, and weight.

Martinez et al. (1993) stratified sampling by location and time of year. It is recommended that sampling under the Galveston Bay Regional Monitoring Program be similarly stratified until available data indicates a change in sampling effort is justified. A detailed description of on-board procedures is provided in Appendix 3 of Martinez et al. (1993). Example data sheets for recording bycatch information and sample descriptions are included in Appendix 3 of Martinez et al. (1993).

6.6.3 QA/QC Considerations

A program that relies on public input for data is susceptible to significant error due to inconsistencies in reporting. The amount of error is minimized by providing participants in the program with detailed instructions on data tabulation and reporting procedures. The *Commercial Harvest Field Operations Manual* (TPWD, 1989) provides such instructions. Quality control can best be achieved through spot checks (i.e., boat visits) in which agency personnel conduct separate tabulations for later comparison with data submitted by the seafood dealers. Aerial surveillance could also be used as a means of verifying the location of harvests reported by commercial fishermen.

6.7 OYSTER POPULATION

Oysters are an economically important species in Galveston Bay that has been commercially harvested since the 1800s. Because of their sessile nature, changes in the abundance and distribution of oysters provides an excellent means for assessing environmental conditions in an area. Monitoring oyster populations is important both because of their economic value and their ecological significance.

Monitoring the condition of Galveston Bay oyster populations involves measurement of both the extent of oyster reefs and the density and condition of the oysters themselves. Throughout much of the following discussion these two aspects of monitoring oyster populations are treated separately. The discussion on data use and limitations is applicable to oyster population monitoring as a whole. There are, however, some distinct difference between the sampling and analytical methods and the QA/QC procedures used in measuring the aerial extent of oyster reefs and the density and condition of the oysters themselves.

6.7.1 Data Use and Limitations

Information on the abundance and distribution of oyster populations will be used to determine whether the following Resource Management Objective is being met:

SP-2: At a minimum, maintain oyster population levels within 50% of 1983-1993 levels.

Monitoring oyster populations will also provide information to support a determination of whether the following Resource Management Objective is being met:

FW-2: Determine annual and seasonal inflow needs to the Bay by 1995.

6.7.2 Sampling and Analytical Methods

This subsection begins with a brief description of sampling and analytical methods that have been used to measure the aerial extent of oyster reefs and the abundance of oysters in Galveston Bay.

Existing Monitoring Programs

The TPWD is the only agency presently conducting routine monitoring of oyster abundance in Galveston Bay. As part of that agency's Resource Monitoring Program, 30 samples are collected each month using a 495 mm wide by 241 mm high oyster dredge. Sampling sites are selected randomly prior to each sampling event from among 126 areas known to contain oyster reefs.

No agency is presently monitoring the extent of oyster reefs in Galveston Bay. A survey of the location, relief, and areal extent of oyster reefs in Galveston Bay has been sponsored by GBNEP. Seismic survey techniques were used to identify and map the extent of oyster reefs and ground-truthing was conducted (using tong or dredge to collect samples) to verify the presence of oyster reefs (Powell and Soniat, 1991). A global positioning system (GPS) navigational system was used to precisely map the location of reefs and ground-truthing samples.

Recommended Monitoring Approach

Only TPWD presently conducts routine monitoring of oyster population density in Galveston Bay. The methods used by that agency are suitable for assessing attainment of the Resource Management Objectives described above and to meet the general objectives of the Regional Monitoring Plan.

The methods and equipment used by TPWD are described in detail in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a). Samples are collected only from known oyster reefs that are at least 0.2 m higher than the surrounding bay bottom, 91.4 m long, 0.5 m wide, and below the mean low tide line on nautical charts. All oyster shell equal to greater than 25 mm in length should be considered in the sample. If shells of live and dead oysters can be culled (separated) then each should be considered separately in counts. If live and dead oysters can not be culled, then only attached live oysters should be counted. For each sample, 19 live oysters should be randomly selected for measurement and the remainder should be counted. Five individuals should be selected from among the 19 live oysters selected measured and the spat (5-25 mm) on one randomly selected side of each should be counted. Five randomly selected dead shells should be selected and the spat similarly counted.

The acoustic profiling techniques described by Simons et al. (1992) and applied in a GBNEP sponsored survey of oyster reefs in Galveston Bay are recommended to be used to measure the areal extent of oyster reefs for the Regional Monitoring Program. These methods provide accurate and precise mapping of oyster reefs at a relatively low cost. The methods have already been used successfully in Galveston Bay, thus providing base line data for future comparisons. However, it is recommended that the accuracy and precision of mapping efforts be increased by running more transects than during the GBNEP survey.

It is recommended that bathymetric data be standardized to a constant datum and processed for analysis by a Geographic Information System compatible with that used for the Habitat Monitoring component of the Regional Monitoring Program.

Additional Considerations

It may also be desirable to monitor oyster condition and infection of dermo. Methods for measuring dermo infection are described in Ray (1966) and Wilson, et al. (1990). It is recommended that a condition index be developed following the methods of the National Oceanic and Atmospheric Administration (NOAA) National Status and Trends Program.

Data Reporting

Species abundance data are recorded on Marine Resource Monitoring Data Sheets and ancillary information recorded on Marine Resource/Harvest Investigation Meteorological and Hydrological Data Sheets. Example copies of these data sheets are included in the *Marine Resource Monitoring Operations Manual* (TPWD, 1993a). Codes for identifying sampling grid locations, species, sex and age of individuals, and the collection method used are also contained in the Operations Manual.

6.7.3 QA/QC Considerations

The *Marine Resource Monitoring Operations Manual* outlines procedures for data coding, data submission, and specific computer programmed data checks. All oyster population monitoring data recording should follow these procedures and be subject to the described data checks. Routine equipment inspections should be conducted at the outset and upon completion of each sampling event to prevent equipment failure in the field and ensure proper operations.

6.8 FISHERIES LOSSES DUE TO IMPINGEMENT AND ENTRAINMENT

Existing information indicates that significant numbers of fish and crustaceans are lost each year due to impingement and entrainment at water intake structures. In 1978 more than 87 million organisms weighing nearly 450,000 kg were impinged at five Houston Lighting and Power (HL&P) generating stations (Palafox, 1993). A number of commercially and recreationally important species were among those most frequently affected. These include white shrimp *(Penaeus setiferus)*, brown shrimp *(Penaeus aztecus)*, blue crab *(Callinectes sapidus)*, Gulf menhaden *(Brevoortia patronus)*, bay anchovy *(Anchoa mitchilli)*, sand seatrout *(Cynoscion arenarius)*, spotted seatrout *(Leiostomus xanthurus)*, and Atlantic croaker *(Micropogonias undulatus)* (Palafox, 1993).

6.8.1 Data Use and Limitations

Monitoring fisheries losses due to impingement and entrainment at water intake structures provides information directly supporting a determination of whether the following Resource Management Objective is being met:

SP-4: Reduce current levels of fish mortality caused by impingement/entrainment by 50% by the year 2007.

To determine whether this objective is being met the monitoring data must be capable of detecting changes of the indicated magnitude (i.e., 50 percent) in statistical comparisons with existing information. Results from this component of the Regional Monitoring Program should also provide information that could be used in selecting appropriate actions for reducing losses if the objective is not being met.

Agency Mandates/Objectives

The TNRCC is responsible for protecting the quality of the state's surface water and groundwater resources. To accomplish this TNRCC develops water quality standards, and regulates point and nonpoint pollution sources.

The TNRCC is primarily concerned with measuring the physical/chemical characteristics of water for comparison with state standards and criteria and permit limitations. Biological data, however, serve a number of purposes that include identifying appropriate designated uses, assessing water quality standards and criteria, and measuring the ecological impact of changes in water quality. Information on fisheries losses due to impingement and entrainment at water intake structures would assist TNRCC in developing permit restrictions for these structures.

This component of the Regional Monitoring Program should provide information on the affects of water temperature and season on impingement and entrainment rates. Existing information suggests that these factors influence survival and the number of individuals impinged or entrained. Such information could be used to select appropriate management options for reducing mortality due to impingement and entrainment.

6.8.2 Sampling and Analytical Methods

Existing Monitoring Programs

The only agency that presently conducts routine monitoring of impingement and entrainment at water intake facilities is TNRCC. Under the TNRCC program two locations (one power plant and one industrial) are sampled twice each year. Past monitoring has also been conducted by Houston Light and Power (HL&P) at five HL&P cooling structures in the Galveston Bay area.

Recommended Monitoring Approach

The TNRCC/HL&P monitoring program provides the most complete data set available describing fisheries losses due to impingement and entrainment at water intake structures. Because of the existing data and the fact that only TNRCC has established protocols, the methods used in that program are recommended for all impingement and entrainment data collection conducted as part of the Galveston Bay Regional Monitoring Program. These methods are described in detail in the TNRCC Impingement and Entrainment Monitoring Protocols (G. Guillen, TNRCC, personal communication). Results of the fisheries and invertebrate monitoring programs will provide population estimates to be used in evaluating the impacts of impingement and entrainment on selected species.

6.9 INTRODUCED EXOTIC SPECIES

Several introduced exotic species present in the Galveston Bay estuary system threaten to displace native species and reduce habitat quality. Monitoring the abundance and distribution of introduced exotic species is necessary to protect these species and their habitat and to provide managers with the information required to develop workable control plans. The Species Population Protection Task Force selected the following three introduced exotic species to be monitored as part of the Galveston Bay Regional Monitoring Program:

- Grass Carp *(Ctenopharyngodon idella)*
- Nutria *(Myocastor coypu)*
- Fire Ants *(Solenopsis spp.)*

Monitoring populations of each species will require different methods and each is therefore treated separately in the following discussion. Grass carp and fire ant populations will be monitored in conjunction with other components of the Regional Monitoring Program.

6.9.1 Data Use and Limitations

Information on the abundance and distribution of introduced exotic species will be used to determine whether the following Resource Management Objective is being met:

SP-6: By the year 2005 reduce the abundance of selected exotic species, including nutria and grass carp, by 10%.

Results from this component of the Regional Monitoring Program will also support a determination of whether the following Resource Management Objective is being met:

HP-6: Improve and protect habitat on 10 major colonial bird nesting sites within 5 years.

6.9.2 Sampling and Analytical Methods

Existing Monitoring Programs

Grass Carp: Grass carp were introduced to the United States in 1963, primarily to control the growth of aquatic vegetation. In 1967, concerns over possible detrimental effects on ecosystems led the State of Texas to prohibit the introduction of grass carp, however, illegal introductions were reported in the early 1980s. In 1981 the Texas Legislature approved an experimental introduction of triploid (functionally sterile) grass carp (Trimm et al., 1989). Recent evidence suggests that grass carp, originating from either illegal introductions or triploid stockings, have successfully spawned in the Trinity River (Robert Howells, personal communication). Furthermore, samples of juvenile individuals collected at a number of locations in Galveston Bay indicate that successful recruitment has also occurred in the estuary.

Presently there is no routine monitoring of grass carp populations in Galveston Bay. The TPWD sampled ichthyoplankton in the Trinity River to determine whether successful reproduction of grass carp is occurring in the area. Sampling was conducted during the spring and summer of 1992 and 1993 at three locations below Lake Livingston. Samples were collected using a 0.5 m conical plankton net cast from a bridge or boat (Robert Howells, personal communication). In addition, juvenile and adult grass carp have been collected during routine fisheries monitoring and fish kill monitoring conducted by TPWD, and incidentally by sport and commercial fisherman. Grass carp data from these sources are summarized by Trimm et al. (1989).

Nutria: Wild populations of nutria first became established in the United States in the 1940s (Kinler et al., 1987). Populations were kept in check in most areas by trapping due to the heavy demand for their pelts in Europe. However, the market for nutria fur declined dramatically in the 1980s and populations are now increasing in many areas. High densities of nutria can cause damage to agricultural crops, levees and shoreline, and marsh vegetation. Recent surveys in Louisiana identified approximately 12,000 acres of marsh that had been damaged by nutria (Greg Linscombe, personal communication). No routine monitoring of nutria populations is presently conducted in the Galveston Bay estuary.

Fire Ants: Fire ants are thought to have been first introduced to the United States in the early 1900s, possibly in ballast or dunnage discarded from ships (Lofgren, 1986). Despite efforts to control their populations, fire ants now occur throughout much of the southern United States from Texas to Florida and as far north as Tennessee. Fire ants are extremely aggressive, stinging insects with a voracious appetite and high reproductive capacity. They have been found to prey on the eggs and young of a number of bird and reptile species and have caused extensive damage to several agricultural crops. In some instances fire ants are believed to have caused local decreases in populations of prey species (Adams, 1986).

Presently there is no routine monitoring of fire ant populations in the Galveston Bay estuary. The Species Population Protection Task Force is concerned about possible impacts of this species on colonial nesting waterbirds in the area. However, no studies to estimate the extent of impacts from fire ant predation on these populations have been conducted.

Recommended Monitoring Approach

Grass Carp: Data collected under the finfish monitoring component of the Galveston Bay Regional Monitoring Program may provide information for measuring changes in the abundance and distribution of adult grass carp in Galveston Bay. However, grass carp are extremely efficient at avoiding nets and do not respond well to shocking (Robert Howells, personal communication). Conventional methods for estimating their population size would probably meet with little success.

A second concern about this species, whether or not it is successfully reproducing in the estuary, is difficult to address based solely on that type of information. Additional sampling to assess reproductive success and recruitment is necessary. Larval sampling would provide the best, most cost effective means of determining whether a viable population exists, and would also provide information about their reproductive life cycle useful for designing control measures if they become necessary. Data from larval sampling could also be used to generate an index of population size in the future.

To determine whether grass carp are successfully reproducing in the Galveston estuary it is necessary to sample ichthyoplankton for viable eggs and larvae. Samples should be collected using a 0.5 m conical plankton net with 1.0 mm mesh. Because the eggs and larvae of this species are slightly negatively buoyant, samples should be collected with an oblique tow from the near-bottom waters (within 0.25 m of the bottom) to the surface (Robert Howells, personal communication).

After allowing the net to completely drain, the cod-end cup should be emptied into the sample container. The cod-end cup should be reattached to the net, the net rinsed from the outside, and the contents of the cup added to the sample container. Samples should be preserved using a solution of 3 to 5 percent buffered (borax or calcium carbonate to a pH of 6.5-7.5) formalin and labeled (Howells, 1985). Sample jars should be filled to prevent eggs and larvae from being splashed onto the sides of the container during transport.

Samples should be processed as described in Howells (1985). All grass carp eggs and larvae should be identified and counted. Descriptions of grass carp larvae are provided in Kilambi and Zdinak (1981) and Conner et al. (undated).

Nutria: Monitoring the size of nutria populations over any large area is difficult due to the habitat these animals are found in and their behavior (Greg Linscombe, personal communication). Nutria have a small home range and their densities fluctuate greatly depending on habitat type (Kinler et al., 1987). Mark and recapture methods are therefore only useful for small areas where relatively continuous habitat conditions exist. It is recommended that population monitoring focus on tracking changes in the relative abundance of nutria by developing an index based on some measure of their activity in selected areas.

Except during periods of extreme cold, nutria are most active at night (Kinler et al., 1987; Dwight LeBlanc, personal communication). Changes in their relative abundance could be monitored using transect or point count methods by spotlighting at night, perhaps in conjunction with alligator surveys. However, in areas of dense vegetation, visual counts would be extremely difficult and could provide inconclusive or misleading data. Alternatively, an index could be established based on some other indicator of their activity such as scat counts, active trail counts, or evidence of feeding activity (Kinler et al., 1987). It is recommended that a special study be undertaken to determine which of these methods would be best suited for the Galveston Bay estuary.

If number of individuals is used as the measure of nutria activity it is recommended that transects or counting stations be located between 1.5 and 2 km apart. It is suggested that transect width and/or the area to be censused at counting stations be determined based on the maximum range of sight in the densest cover to be monitored. Counting time at each station or speed along the transects should be standardized. For other measures of nutria activity (e.g., scat counts, active trail counts, or evidence of feeding activity) it is recommended that sampling be done along established transects (2 km apart). It is recommended that specific criteria for counting any measure other than number of individuals be established (e.g., for determining whether a trail is active).

Fire Ants: A major concern surrounding the abundance and distribution of fire ants centers around their impact on colonial nesting waterbirds. Monitoring of this group, therefore, should be done in conjunction with the colonial waterbird nesting habitat component of the Regional Monitoring Program.

Two methods can be used to determine the extent of the impact of fire ants on colonial nesting waterbirds. It is recommended that their abundance and distribution be monitored by counts of their mounds in the vicinity of waterbird nesting colonies. Mounds should be counted annually prior to the nesting season during colonial waterbird nesting habitat surveys. It is also recommended that the impact of fire ants on these colonies be estimated by surveys for the carcasses of juveniles and eggs preyed upon by the fire ants. These surveys should be conducted at selected nesting colonies at the end of the nesting season.

Available Alternative Monitoring Approaches

Grass Carp: Grass carp spawn during a narrow temperature range (18-20° C) and demonstrate rapid development until hatching (approximately 24 hours) and through the yolk sac stage (24-36 hours) (Robert Howells, personal communication). During early development the eggs and larvae move with the current down stream from the spawning area. Frequent sampling should be conducted during the period when spawning and early development are likely to be occurring (i.e., when water temperatures are near 18-20° C). Several stations should be sampled in areas where spawning is likely to occur and downstream of these locations. Although 0.5 m plankton nets are suitable for collecting grass carp eggs and early larval stages, individuals larger than 12 mm are collected less frequently by this method and may be able to avoid the net (Robert Howells, personal communication). Bongo nets are designed to reduce net avoidance by eliminating the need for a harness that extends in front of the net. These nets consist of paired conical plankton nets that are rigged adjacent to one another by a rigid frame. A single line is attached between the two nets and weighted at its bottom allowing the net to be fished at any selected depth without the need for harnesses extending in front of the mouth of the nets.

Nutria: Rather than monitoring changes in nutria populations it may be desirable to focus on monitoring the extent of nutria damage in marshes surrounding Galveston Bay. Such an approach has been used successfully for monitoring marshes in Louisiana by the Louisiana Department of Wildlife and Fisheries (Greg Linscombe, personal communication). Six-hundred miles of transects are flown by helicopter and the positions of damaged areas are fixed using a global positioning system (GPS). On-site surveys are made to assess the severity of the damage. Damage is classified in one of three categories, heavy feeding, moderate damage, or heavy damage. In May and December of 1993 marsh damage surveys were conducted as part of the Barataria-Terrebonne National Estuary Program in Louisiana.

6.9.3 QA/QC Considerations

Grass carp eggs and larvae can be difficult to identify and are similar to other native species occurring in the Galveston estuary in many respects. Samples should be sent to Heart of the Hills Fisheries Research Station or the Larval Fish Laboratory, Colorado State University for verification.

6.10 THREATENED AND ENDANGERED SPECIES

A number of Federally listed threatened or endangered species occur in the Galveston Bay estuary. Because of the additional protection afforded these species under the Federal Endangered Species Act, information on their abundance and distribution is particularly important to regulators. Species whose populations are in danger of extinction due to human activities are valuable indicators of environmental condition. Management actions taken to protect threatened or endangered species or their habitat are easily evaluated by changes in species abundance.

The Species Population Protection Task Force identified the following species as indicators for threatened and endangered species in Galveston Bay:

- brown pelican
- southeastern snowy plover
- Kemp's Ridley sea turtle
- Texas diamondback terrapin

Although the bird population monitoring described in Section 6.3 will likely provide some data on brown pelican and southeastern snowy plover populations, additional sampling of these species is recommended. Similar methods could be used to census either of these species and suggested methods are therefore described jointly (i.e., bird populations). Monitoring Kemp's Ridley sea turtle and Texas diamondback terrapin populations require different methods and each is treated separately in the following discussion.

6.10.1 Data Use and Limitations

Information on the abundance and distribution of threatened and endangered species will be used to determine whether the following Resource Management Objective is being met:

SP-5: Increase populations of endangered and threatened species.

Agency Mandates/Objectives

The Endangered Species Act provides protection for species that are in danger of extinction over all or a significant portion of their range or are likely to become so within the foreseeable future. Section 9 of the Act makes it unlawful for any person subject to the jurisdiction of the United States to take, import, export, possess, sell, deliver, carry, transport, or ship any listed species. "Take" includes harassing, harming, pursuing, hunting, shooting, wounding, killing, trapping, capturing, collecting, or attempting to collect. Furthermore, Section 4 of the Act requires the National Marine Fisheries Service (NMFS) or the U.S. Fish and Wildlife Service to develop Recovery Plans for all listed species. Monitoring the abundance and distribution of threatened and endangered species provides information that will be helpful in making decisions regarding the listing or delisting of species.

6.10.2 Sampling and Analytical Methods

Existing Monitoring Programs

Kemp's Ridley sea turtle: Presently there is very little organized monitoring of sea turtles along the Texas coast and most records have probably resulted from opportunistic sightings rather than organized sampling (Charles Caillouet, personal communication). Surveys to locate stranded sea turtles along the southeast coast of the United States are conducted by the Sea Turtle Stranding and Salvage Network (STSSN). These surveys represent the only ongoing, long-term effort to monitor sea turtle populations along the Texas coast. The NMFS Southeast Fisheries Science Center, Galveston Laboratory maintains records of strandings, sightings, and incidental catches of shrimp trawls and hook and line fisheries (Manzella and Williams, 1992). Efforts have been made to increase public reporting of sea turtle sightings by placing signs describing various sea turtle species and providing contact information.

Texas A&M University and NMFS have recently begun a tagging study in Galveston Bay to investigate the impact of dredging activities on the Kemp's Ridley sea turtle. Up to 20 individuals will be tagged with radio (12) or satellite (8) tags so that their movements along the Texas coast can be tracked. In addition, Texas A&M University will establish sea turtle capture/monitoring stations at three locations along the coast, including Bolivar Roads. Pilot studies to determine the population status of Kemp's Ridley sea turtle in these areas will also be initiated (Andre Landry, personal communication).

Texas diamondback terrapin: A public information and reporting system has recently been established for reporting the occurrence of Texas diamondback terrapin in crab traps. Efforts to encourage the public to use crab trapping methods that are less likely to impact terrapin have also begun. Prior to these efforts there was no monitoring of Texas diamondback terrapin abundance or distribution in Galveston Bay.

Bird populations: Three existing monitoring programs that census bird populations in the Galveston Bay estuary are described in Section 6.3. In addition to these programs, the National Audubon Society conducts an annual Christmas Bird Count (CBC) in the area. The CBC tallies all birds within a 24-km diameter area by species at five areas surrounding the Galveston Bay estuary. Four of these count areas (Bolivar Peninsula, Galveston, Houston, and Old River) have been censused on a nearly continuous basis since 1965 (Slack et al., 1992). The fifth count area (Armand Bayou) has been censused since 1982. Slack et al. (1992) found that the brown pelican was frequently reported in the CBC and feel that the data would be suitable for analysis of trends in that species.

None of the existing monitoring programs recorded southeastern snowy plover frequently enough to provide reliable population estimates for that species.

Recommended Monitoring Approach

Kemp's Ridley sea turtle: Due to their low population levels and migratory nature, quantitative measures of Kemp's Ridley sea turtle abundance and distribution would require extensive sampling. The methods used by the STSSN to collect information on sea turtles could provide useful information on the occurrence of Kemp's Ridley sea turtle in Galveston Bay. In the long term such monitoring would provide an index of relative population size. Information about the distribution of Kemp's Ridley sea turtle within the Galveston Bay estuary will allow managers to identify high use areas and see that these areas are protected from human impacts.

It is recommended that a program be initiated to increase public awareness and knowledge of sea turtles and thereby increase public reporting of stranded turtles throughout the Galveston Bay estuary. Information displays could be constructed at public access points in areas were stranded sea turtles have most frequently been observed (e.g., based on Manzella and Williams, 1992). Such displays would encourage public participation and increase awareness. Visitors could be requested to provide information about the amount of time they spent in an area, any turtles observed, and other pertinent information.

It is recommended that information about public use patterns in the vicinity of displays also be collected. This will enable investigators to assess whether changes in the number of reportings are due to changes in sea turtle distributions or to changes in the level of human activity in an area.

Texas diamondback terrapin: It is recommended that a public reporting program be initiated to provide information on the number of Texas diamondback terrapin occurring in crab traps. Although this information could not be used to generate an estimate population size, it would provide an index of population size and could also provide valuable information on the significance of the impact crab trapping is having on terrapin populations.

Reporting cards could be made available at boat launches and public access areas. It is recommended that a display describing the Texas diamondback terrapin and its ecology along with instructions for filling out reports be provided. The display should stress the importance of filling out and submitting the report cards regardless of whether terrapin were caught. Table 6.6 lists suggested information to be requested in the volunteer reporting program.

Table 6-6. TERRAPIN REPORTING INFORMATION

Date
Fishing location
Number of traps
Time fishing was begun
Time fishing ended
Total fishing time (hours)
Approximate time each trap was fished before being checked (hours)
Number of Texas diamondback terrapin caught
Type of bait

Bird populations: It is recommended that brown pelicans and southeastern snowy plover be censused using the point count method. Point counts are conducted by visiting a designated point and counting, either through direct counts or call counts, the number of species and individuals observed within a specified time period. To generate an accurate estimate of population size using this method individuals must be randomly distributed within the defined habitat and the area being censused must be representative of that habitat as a whole. An estimate of the aerial extent of a species habitat must also be available to estimate population size using this method. Without a measure of the total extent of habitat, this method provides an index of population size that can be used for estimating relative changes in a population.

It is recommended that sampling points for brown pelican and southeastern snowy plover be established at known high use areas for these species. Existing or proposed sampling locations for the Shorebird Surveys, Texas Colonial Waterbird Counts (see Section 6.3), or the CBC, should be considered as sampling locations. It is recommended that sampling be conducted during morning low tides of the spring tide cycle each month that sampling is conducted. As both of these species are migratory with regard to there use of Galveston Bay it is suggested that efforts be focused on establishing an index to track relative changes in population size rather than providing an estimate of population size.

Available Alternative Monitoring Approaches

Kemp's Ridley sea turtle: Intensive studies could be conducted using telemetry to track the movement of individual turtles in the Estuary. It is recommended that any such work follow the methods being used in the joint Texas A&M University and NMFS study. Turtles can be captured using entanglement nets or standard bait casting nets deployed along the jetties and in other areas where sea turtles are known to occur in Galveston Bay. Radio tagging of captured individuals will allow their movements to be tracked throughout Galveston Bay.

It is recommended that tagging only be undertaken if results of the Texas A&M University-NMFS study indicate that such methods could provide data suitable for estimating population size. Although useful information about the movement of Kemp's Ridley sea turtles in Galveston Bay could be gained through a limited tagging program, estimating population size would require a significantly greater effort. The potential for harming individuals needs to be carefully considered before subjecting an endangered species to such an intensive sampling program.

6.10.3 QA/QC Considerations

Kemp's Ridley sea turtle: In public access areas where permanent employees are stationed, training/orientation should be provided so that these employees are able to confirm reported sightings.

CHAPTER 7
PUBLIC HEALTH

The Galveston Bay estuary is the largest source of seafood in Texas, and one of the major oyster producing areas in the country. Commercial and recreational fishing represents an almost one-billion dollar industry, and molluscan shellfish (e.g., oysters) and other seafood (e.g., crabs, shrimp, and finfish) harvested from Galveston Bay are consumed by millions of individuals. Maintenance of adequate public health standards of estuarine seafood is essential for the protection of the consuming public, and is critical for the long-term stability of seafood-derived industries within Texas.

Consumption of bioaccumulated toxicants and bacterial pathogens in fish and shellfish tissue and contact with bacterial pathogens during water-based recreational activities are the three major public health concerns associated with the environmental management of Galveston Bay. Because oysters are often eaten raw, contaminated oysters can threaten human health because they are often eaten raw, contaminated oysters have the potential to pose a serious threat to human health. Consumption of other fish, in which toxic contaminants have bioaccumulated can also lead to adverse health effects for the consumer. Contact and non-contact recreational activities in contaminated waters (e.g., swimming, boating) can also present hazards to human health.

Three Resource Management Objectives have been developed in the Galveston Bay Plan to support public health protection:

PH-1: By the year 2000, reduce the risk of consumption of Galveston Bay seafood containing tissue concentrations of toxic substances above risk level standards established by the Texas Department of Health (TDH).

PH-2: Increase the oyster reef areas open to harvest by 25 percent on a spatial and temporal basis by August 1995, as compared to a 1988 baseline.

PH-3: By the year 2000, establish a contact recreation advisory program in all areas of the estuary commonly used for contact recreation.

Monitoring of levels of fecal coliforms in Galveston Bay waters and concentrations of contaminants in the edible tissue of target fish and shellfish are necessary to fulfill these monitoring objectives.

7.1 PATHOGENS

It is not possible to routinely identify and enumerate the many different human pathogens that can be found in estuarine waters. Thus, indicator groups have been used to monitor health risks. In the past, total coliform bacteria, and more recently, fecal coliforms have been used as indicator organisms.

Other microbiological organisms, including *Escherichia coli* (*E. coli*), fecal streptococcus, and enterococcus have been used or recommended as indicators in either USEPA guidance or state water quality standards (Jensen and Su, 1992). However, the Texas water quality criteria for contact and non-contact recreational waters, and the water quality criteria for shellfish growing waters, as defined by the National Shellfish Sanitation Program (NSSP) use only fecal coliform bacteria as indicators.

7.1.1 Data Use and Limitations

The assessment of pathogen contamination is an essential component of a monitoring program concerned with risks to human health and economic viability of an estuary. Monitoring of fecal coliform concentrations provides essential information relating the temporal and spatial distribution of pathogens to regulatory actions, such as issuing contact health advisories and closing shellfish growing areas to harvesting. Furthermore, monitoring of effluent discharges can be used to identify potential sources of pathogens and to support the attainment of water quality standards.

Although fecal coliform monitoring methods have been widely accepted for many years by public health authorities, it is by no means an ideal indicator. One major limitation of the test is that it is subject to many false positive results (that is, it may indicate that a health risk exists when one does not exist). On the other hand, the test does not directly measure several of the naturally occurring pathogens, such as *E. coli* and *Vibrio vulnificus*, which may be harmful if contacted or consumed.

Monitoring of fecal coliform levels in Galveston Bay will provide data to support the determination of whether the following Resource Management Objectives are being attained:

PH-2: Increase the oyster reef areas open to harvest by 25 percent on a spatial and temporal basis by August 1995, as compared to a 1988 baseline.

PH-3: By the year 2000, establish a contact recreation advisory program in all areas of the estuary commonly used for contact recreation.

Agency Mandates/Objectives

With respect to the human health consequences of seafood processing and consumption, the TDH's Division of Shellfish Sanitation Control (DSSC) is responsible for monitoring and harvesting activities within the State of Texas under Chapter 436 of the Texas Health and Safety Code (Hadden and Riggin, 1993). The chapter authorizes the DSSC to monitor and ensure the public safety of fish and shrimp, shellfish (oysters, mussels, and clams), and crabs taken from Texas water for human consumption. The current DSSC monitoring procedures follow the *National Shellfish Sanitation Program Manual of Operations*, published by the Shellfish Sanitation Branch of the U.S. Food and Drug Administration (USFDA and ISSC, 1990).

In part, the procedures require a sanitary survey and classification as to the suitability of the areas to produce shellfish fit for human consumption. The sanitary survey consists of three components:

- a survey of the shoreline to evaluate all actual and potential pollution sources
- an evaluation of hydrographic (water dynamics, dispersion) and meteorlogical (quantity and frequency of rains, effects of winds) effects
- the collection and analysis of water samples for fecal coliform concentrations.

All three components are used to determine the status of harvest areas as either approved, conditionally approved, or prohibited for harvesting. The most variable parameters are rainfall, river flow, and coliform count. Rainfall and river stage are collected daily from the National Weather Service. Fecal coliform concentrations are estimated from water samples collected by TDH from about 112 sampling stations throughout the bay, each one of which is monitored 12 to 30 times a year (Jensen and Su, 1993).

Bacteriological monitoring, using fecal coliform counts, is also performed by the TNRCC, as part of its responsibility for protecting the quality of the state's surface water and groundwater resources. A wide suite of parameters are measured in conjunction with the coliform concentration estimates to monitor ambient water and sediment conditions. Each year, approximately 240 samples are collected by the TNRCC from 68 stations for coliform and other physical and chemical analyses.

Bay waters are deemed unacceptable for recreational use if fecal coliform concentrations exceed USEPA and State of Texas water quality critera of 200 colonies/100 mL for contact recreation and 2000 colonies/100 mL for noncontact recreation. However, no contact recreation advisory program is currently in place within the bay.

7.1.2 Sampling and Analytical Methods

Collection methods

Collection of near-surface water samples is a straightforward procedure that can be performed with hand-held glass or plastic containers. Procedures that are used by TDH and TNRCC differ mainly in the location and timing of the collections. TDH, charged with the protection of public health, is concerned with forming "a profile for periods defining adverse pollution conditions that reflect adverse meteorological, hydrographic, seasonal, and point sources of pollution," (USFDA and ISSC, 1990). TNRCC monitoring data is used, in part, to assess long-term trends in water quality, and thus are concerned with ambient conditions, and not potential worse-case conditions.

Procedures followed by TDH are outlined in:

> *National Shellfish Sanitation Program Manual of Operations.*
> USFDA and ISSC, 1990.

This manual specifies that: *Recommended Procedures for the Examination of Seawater and Shellfish.* (APHA, 1970) shall be followed for the collection, transportation, and examination of samples of shellfish and shellfish waters. Methods and techniques described are reported to be identical to those of *Standard Methods for the Examination of Water and Wastewater, 18th ed.* (APHA, 1992).

Ancillary data collected during field sampling includes water, temperature, dissolved oxygen concentration, and salinity. Observations of weather conditions (air temperature, wind direction and speed) are recorded as well. Rainfall data and river stage information for the Trinity River are updated daily. Based on statistical analyses of historical studies, the TDH uses this data to determine if closures of specific areas are to be made (Hadden and Riggin, 1993).

TNRCC sample collection protocols for bacterial determinations are defined in the *Texas Surface Water Quality Standards*, Section 307.9 (15 TexReg 7495). Again, procedures for the collection and preservation of samples are required to be in accordance with *Standard Methods.*

Analytical methods

Both TDH and TNRCC stipulate the same reference, *Standard Methods*, but different analytical procedures to determine fecal coliform counts. The multiple-tube most probable number test (MPN) is performed by the THDH, as required by the NNSSP. The membrane filter (MF) method is used by the TNRCC. Complete details of the two laboratory test procedures are found in *Standard Methods* (APHA, 1992) and a concise summary of each is presented in Appendix B of Jensen and Su (1992).

While Standard Methods indicates the two procedures produce equivalent results, TDH follow the NSSP requirement to use the MPN procedure. This requirement resulted from NSSP comparisons of the two methods that found the MF procedure yields lower colony counts in turbid water. Apparently high suspended solids content can reduce the ability of the growth media to reach bacteria that would otherwise become countable colonies (Jensen and Su, 1992).

Recommended Monitoring Method

Both methods are required to provide the necessary data to assess the two Resource Management Objectives. The TDH MPN method is required by state and federal regulations, the TNRCC method using the membrane filter method will continue to be used to as an ambient monitoring method to support Galveston Bay Regional Monitoring Program. Although TNRCC results cannot be used directly to supplement NSSP monitoring requirements, both datasets can be used for monitoring the status and trends of fecal coliform bacteria within the bay.

Alternative Monitoring Approaches

In the case of human health protection monitoring, alternative approaches focus on different indicator species than alternative methods of collection or analysis. The use of other indicators of human pathogens have been studied extensively and a brief description of the characteristics of two candidate bacteria are discussed.

E. coli is a member of the coliform bacteria population that may be used to indicate fecal sources. It is a normal and dominant inhabitant of the mammalian digestive tract. However, the use of *E. coli* as an indicator organism is somewhat hampered by the facts that it is not a single species; it can be found outside the human intestinal tract; other organisms found in water that do not represent fecal pollution possess some of the attributes of *E. coli*; and identical genera are found in human and other animal intestinal tracts (Jensen and Su, 1992).

Enterococci belong within the fecal streptococcus group, whose normal habitat is the gastrointestinal tract of warm-blooded animals, and their presence in surface waters is an indication of fecal contamination. Studies at marine and fresh water bathing beaches indicated that swimming-associated gastroenteritis was directly related to the quality of the bathing water and that enterococci were the most efficient bacterial indicator of water quality (Cabelli et al., 1982). USEPA recommends enterococci as the only bacterial indicator for marine water in its *1986 Water Quality Criteria* (USEPA, 1986b).

Both of these bacteria possess some advantages over fecal coliforms as indicator organisms. But the regulatory mandates of the TDH to follow procedures described in the NSSP effectively prevent changes in methods. Therefore, for the foreseeable future, the fecal coliform group is likely to continue to be the basis for much of the water quality testing and regulatory decision making regarding both shellfish harvesting and contact recreation. However, members of the GBNEP Public Health Task Force have strongly recommended that the use of other bacteriological indicators (e.g., enterococcus, *E. coli*) be considered for inclusion into the regional monitoring program at a later date.

7.1.3 QA/QC Considerations

TDH guidelines require that samples be collected, transported, and analyzed in accordance with standard methods as found in the following documents:

Standard Methods for the Examination of Water and Wastewater, 16th ed. Washington, DC. American Public Health Association, American Water Works Association, Water Pollution Control Federation; 1985. (The latest edition is the 18th, published in 1992).

Bacteriological Analytical Manual of the Division of Microbiology, Center for Food Safety and Applied Nutrition, 6th ed. Washington, DC. US Food and Drug Administration, 1984.

Official Methods of Analysis of the Association of Official Analytical Chemists, 14th ed. Arlington, VA. Association of Official Analytical Chemists, 1984.

The NSSP further specifies that the state shellfish control agency (TDH, in this case):

a. Provide an internal monitoring program to evaluate laboratory facilities, equipment, and materials

b. Participate in FDA-sponsored proficiency testing programs and on-site laboratory evaluations.

c. Provide proper training and supervision for laboratory personnel.

d. Maintain records of analytical performance, analytical results, and equipment operations and maintenance.

f. Evaluate laboratories supporting state shellfish programs pursuant to established NSSP guidelines.

TNRCC has established QA procedures for the entire range of sampling and analytical efforts conducted by the agency. For example, all sample collection is required to be conducted according to procedures found in the latest edition of:

Standard Methods (APHA, 1992), or

Methods for the Chemical Analysis of Water and Wastes. 3rd Ed. EPA 600/4-79-020. Washington, DC. US Environmental Protection Agency, 1983, or

Biological Field and Laboratory Methods for Measuring the Quality of Surface Waters and Effluents. Washington, DC. US Environmental Protection Agency, 1973.

Sample handling procedures, and physical, chemical, and microbiological analytical procedures for effluents are required to meet the specifications of *Standard Methods* and the regulations published in 40 Code of Federal Regulations Part 136, pursuant to the Federal Water Pollution Control Act. Required interlaboratory quality control practices are as recommended in the latest edition of the manual:

> *Handbook for Analytical Quality Control in Water and Wastewater Laboratories.* EPA 600/4-79-019. Cincinnati, OH. US Environmental Protection Agency, 1979.

7.2 TOXIC CONTAMINANTS

Contamination of aquatic resources by toxic chemicals is a well-recognized problem. Each year, millions of pounds of fish and shellfish, caught by commercial and sport fishermen in Galveston Bay are consumed. However, little or no testing of edible tissues for toxic contamination by heavy metals, organic pollutants, and pesticides has been conducted to assess or monitor public health risks resulting from bioaccumulation (Brooks et al., 1992).

Toxic contamination and bioaccumulation monitoring can provide data to directly support and monitor the attainment of the Public Health Resource Management Objective as stated below:

> PH-1: By the year 2000, reduce the risk of consumption of Galveston Bay seafood containing tissue concentrations of toxic substances above risk level standards established by the Texas Department of Health (TDH).

The regulatory framework for ensuring that fish are safe to eat is similar to that for oysters. Testing procedures are governed exclusively by state laws. At present, there are no FDA regulations addressing pollution levels for fish consumption. In Texas, as for shellfish, the DSSC oversees human health aspects of the consumption and processing of fish under Chapter 436 of the Texas Health and Safety Code (Hadden and Riggin, 1993).

7.2.1 Data Use and Limitations

Health problems and regulation of fish differ in significant ways from bacteriological contamination of oysters. With the exception of fish that have not been properly stored, the human health consequences from eating contaminated fish are usually long-term and subtle, in contrast to the immediate effects of eating bad oysters. Fish are mobile, while oysters are immobile. Thus, while the safety of oyster consumption can be indicated by sampling the surrounding waters, the same is not true for fish. As well as having to test the tissue of the fish itself, it is also necessary to test for a wide suite of possible contaminants. To add to the complexity, a number of fish and a number of different species of fish must be tested before reasonable decisions can be made as to the safety of a species for human consumption.

No routine ambient monitoring of toxic contaminant levels in fish tissue is presently being carried out in Galveston Bay. TNRCC and TDH do collect and sample tissue on an episodic basis, in response to oil spills, toxic leaks, and other accidental releases into the bay, although the focus of each agency is different. TNRCC's effort is in support of water quality monitoring, while the primary concern of TDH is human health risk. Part of the reason for the lack of routine monitoring is the cost associated with tissue analyses, which can range from $1,200 to $2,500 per sample, depending on the suite of parameters tested.

NOAA's Status and Trends Mussel Watch Program is designed to monitor the current status and long-term trends of selected environmental organic and trace metal contaminants along the Atlantic, Pacific, and Gulf coasts of the U.S. by measuring the concentrations of these contaminants in bivalves. Six sites within Galveston Bay are sampled every two years. The data from this program is designed to monitor large-scale trends throughout the nation and is too sparse to provide detailed information on ambient conditions within Galveston Bay.

7.2.2 Sampling and Analytical Methods

Tissues are sampled for a variety of reasons, including the assessment of human health risk and the investigation of pollution sources. However, tissue sampling and analysis are costly and time consuming, and decisions based on these data can have significant impacts on different sectors of society. For these reasons it is important to maximize the comparability of data derived from tissue analysis by strictly following sampling guidelines for every sampling event (DSSC, no date). These guidelines should be made available to all agencies and organizations that may be involved in tissue sampling efforts, whether for human health concerns or species propagation and health studies. Both TDH and TNRCC have existing and similar protocols for tissue collection and preparation (DSSC, no date; TWC, 1993).

Recommended Methods

The TDH protocols, *Tissue Sampling Guidelines* (DSSC, no date), are specifically designed for the sampling of edible tissues and so are recommended to be used for monitoring efforts focusing on human health issues.

Table 7-1 lists those indicator species recommended by the Public Health Protection Task Force members.

As discussed above, TDH laboratories perform (or supervise contract laboratories) all the analyses for toxic contaminants in fish and shellfish tissue for samples collected in Galveston Bay. The continued use of these existing laboratory methods is recommended to support the public health Resource Management Objectives.

Table 7-1. RECOMMENDED INDICATOR SPECIES FOR PUBLIC HEALTH PROTECTION

Shellfish
Blue crab
Oyster
Fish
Black Drum
Southern Flounder
Atlantic Craoker
Seatrout
Redfish

USEPA-recommended analytical methods are used for all tissue analyses. For determinations of trace metal concentrations, the references used are:

Methods for the Determinations of Metals in Environmental Samples. EPA 600-4-91-010. Cincinnati, OH. US Environmental Protection Agency, 1991.

Methods for the Chemical Analysis of Water and Wastes 3rd ed. EPA 600/4-79-020. Cincinnati, OH. US Environmental Protection Agency, 1983.

For specific metals, the following methods are used (S. Dubois, 1994):

Preparation and digestion	200.3 (for all except mercury)
Mercury	245.6
Arsenic	206.3 (hydride method)
Cobalt and zinc	200.7 (using ICP-inductively coupled plasma spectroscopy)
Lead	239.2 (graphite furnace).

USEPA has published interim procedures for sampling and analysis of priority pollutants in fish tissue (USEPA, 1981); however, official USEPA-approved methods are available only for the analysis of low parts-per-million concentrations of metals in fish and shellfish tissue (USEPA, 1991b).

Alternative Methods

It is recommended that the fish sampling and analysis guidance presented in *Guidance for Assessing Chemical Contaminant Data for Use in Fish Advisories* (USEPA, 1993b) be incorporated in the tissue collection and preparation protocols issued by TDH. The advantage of more detailed and more rigorous QA/QC methods will enhance the quality and comparability of data, especially when collected by staff from different agencies.

7.2.3 QA/QC Considerations

QA procedures sample collection and preparation are documented in the DSSC sampling guidelines (DSSC, no date). The majority of EPA-approved analytical methods include method-specific QA procedures. For overall laboratory QA/QC procedures, TDH follow EPA guidelines described in:

> *Interim Guidelines and Specifications for Preparing Quality Assurance Project Plans*. QAMS-005/80. Washington, DC. US Environmental Protection Agency, 1980.

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Appendix B

Thematic Layer Name- LandCover_TM

Thematic Layer Description- LandCover_TM is a Landsat Thematic Mapper (TM) based Land cover/Land use classification developed by the National Oceanic and Atmospheric Administration (NOAA) Coastal-Change Analyses Program (C-CAP) and modified by the Texas Parks and Wildlife Department (TPWD). The classification system is a hierarchical system combining characteristics from the National Wetland Inventory system (Cowardin *et al.*, 1979) and the Anderson Land cover/Land use system (Anderson *et al.,* 1976) customized for satellite derived data.

Data Structure-

Field	Defined	Type	Length
1	Name	C	25
2	Division	I	3
3	Super-Class	I	3
4	Class	I	3
5	Sub Class	I	3

The Field 1 character string corresponds to the Land Cover Type (i.e. UPLANDS, Urban Woodlands, etc.). The integer value in remaining fields are the Class Number.

Attribute Descriptions- LandCover_TM is structured as follows:

X	**DIVISION**
X.X	Super Class
X.XX	Class
X.XXX	Sub Class

C-CAP/TPWD Coastal Land Cover Classification System

CLASS NUMBER	LAND COVER TYPE
1	1.0 **UPLANDS**
2	1.1 Developed Lands
3	1.11 High Intensity
4	1.12 Low Intensity
81	1.13 Urban Woodlands
5	1.2 Cultivated Lands
6	1.21 Croplands (Active, vegetated)
7	1.22 Agricultural wetlands (Rice Fields)
8	1.23 Fallow crop lands
9	1.3 Grasslands
10	1.31 Managed pastures

11	1.32 Prairie
12	1.4 Woody Lands (Shrub-Scrub/Forested)
13	1.41 Deciduous
14	1.42 Evergreen
15	1.43 Mixed
16	1.5 Bare Lands
17	1.51 Unvegetated non-saline lands
18	1.52 Levees and Spoil Deposition
19	2.0 **WETLANDS** (Defined to exclude Bottoms, Reefs, Nonpersistent Emergent Wetlands, and Aquatic Beds, all of which are covered under 3.0, Water and Submerged Land)
21	2.2 Marine/Estuarine Unconsolidated Shore (Beach, Flat, Bar)
23	2.22 Sand (Salt and Sand Flats)
24	2.23 Mud/organic Flats
25	2.24 Algal Flats
26	2.3 Estuarine Emergent Wetland
27	2.31 Haline (Salt Marsh)
28	2.311 Low Salt Marsh
29	2.312 High Salt Marsh
30	2.32 Mixohaline (Brackish March)
31	2.321 Low Brackish Marsh
32	2.322 High Brackish Marsh
33	2.33 Oligohaline (Intermediate March)
34	2.331 Low Intermediate Marsh
35	2.332 High Intermediate Marsh
36	2.34 Salt Prairie
37	2.4 Estuarine Woody Wetland (Shrub-Scrub/Forest)
38	2.41 Deciduous
39	2.42 Evergreen
40	2.43 Mixed
49	2.7 Palustrine Unconsolidated Shore (Beach, Flat, Bar)
51	2.72 Sand
52	2.73 Mud/Organic
53	2.8 Palustrine Emergent Wetland
54	2.81 Permanent
55	2.82 Wet Prairie
56	2.9 Palustrine Woody Wetland (Shrub-Scrub/Forested)
57	2.91 Bottom land/Riparian Woodland
58	2.92 Swamps Cypress-Tupelo
59	2.93 Deciduous Shrub-Scrub (Tallow-Baccharis)

60	3.0 **WATER AND SUBMERGED LAND** (Defined to include wetland deep water habitats with surface water but lacking trees, shrubs, and emergent vegetation)
61	3.1 Water (Bottoms and undetectable reefs, aquatic beds nonpersistent emergent wetlands
82	3.10 Shallow Water
67	3.2 Marine/Estuarine Aquatic Bed
69	3.32 Rooted Vascular (e.g. seagrass)
70	3.321 Dense Beds
71	3.322 Sparse Beds

* Mapping resolution is based on 28 meter pixels. Minimum mapping unit is .4 ha. Italicized **Class Number** values represent classes developed through interpretation of aerial photography and produced at a scale of 1:24,000.

TEXAS PARKS AND WILDLIFE DEPARTMENT C-CAP LAND COVER DESCRIPTIONS (modified from "NOAA COAST WATCH CHANGE ANALYSIS PROJECT GUIDANCE FOR REGIONAL IMPLEMENTATION" Ver. 1.0).

NAME, CLASS
DESCRIPTION

1.0 UPLANDS, Class #1
The Uplands division consists of five super-classes: Developed lands, Cultivated Lands, Grasslands, Woody Lands and Bare Lands. Upland classes are adapted from Level I classes in the USGS Land Use/Land Cover Classification System (Anderson *et. al.,* 1976). Refined through manual delineation of imagery.

1.1 Developed Lands, Class #2
Includes areas of intensive anthropogenic use. Much of the land is covered by structures and impervious surfaces.
1.11 High Intensity Developed Land, Class #3, contains little or no vegetation. This includes industrial sites, large buildings, interstate.
1.12 Low Intensity Developed Land, Class #4, contains mixes of structures, bare lands and vegetated lands. Typically suburban settings.
1.13 Urban Woodlands, Class #81, contains mixes of domesticated woodlands and ornamentals largely influenced by woody vegetation within suburban landscapes.

1.2 Cultivated Lands, Class #5
Includes herbaceous croplands, rice fields and fallow fields. Seasonal spectral signatures, geometric field patterns and road network patterns help identify this land cover type. Always associated with agricultural land use. Refined through manual delineation of imagery.
1.21 Croplands (vegetated and active), Class #6, are non-flooded vegetated field, active or stubble. Typified be sorghum, milo, oats, cotton etc.
1.22 Agricultural Wetlands, Class #7, are flooded rice fields, active or senescent. Spectrally similar to naturally occurring wetlands.
1.23 Fallow Croplands, Class #8, plowed or exposed agricultural croplands. Spectrally similar to Bare Lands and some Developed Lands.

1.3 Grasslands, Class #9
Differs from Rangeland in Anderson *et. al.,* (1976) by excluding shrub-brush lands. Managed grasslands are maintained by human activity such as fertilization and used for grazing or for growing and harvesting hay for animal feed. Managed grasslands are spectrally similar to some cultivated lands. Prairie is naturally occurring grasses and forbs which are not fertilized, cut, tilled or planted regularly but often burned. Managed pastures refined through manual delineation of imagery.
Class 1.31 Managed pastures, Class #10, spectrally separated from croplands as having less biomass and tends to be associated within developed sites. Typically vegetated roadsides, improved bermuda pastures, fields in developed settings, etc. Often referred to as lightly vegetated sites.

Class 1.32 Prairie, Class #11, non-wet grasslands areas broken out by standard classification in undeveloped sites. Prairie is moderate to heavily vegetated (herbaceous) non-cropland sites and is distinguished from wetlands due to restricted hydrology. Prairie sites are often the drier sites within Coastal Prairie or Salt Prairie associations and used as rangeland.

1.4 Woody Lands, Class #12
Includes non-agricultural trees and shrubs. The category alleviates the problem of separating various sizes of trees and shrubs using satellite remote sensor data. The three classes are distinguished by spectral values.
1.41 Deciduous (non-coniferous), Class #13 dominated (>70%) by upland broad leaf woody vegetation such as *Ulmus crassifolia, Celtus laevigata, Quarcus alba, Quarcus virginiana* (while not deciduous is included), etc.
1.42 Evergreen (coniferous), Class #14 predominantly (>70%) one or more of four pine species *Pinus teada, P. elliotti, P. palustris* and *P. echniata* in the southeast.
1.43 Mixed, Class #15 Mixed associations exhibiting spectral values between the deciduous and evergreen classes.

1.5 Bare Lands, Class #16
Composed of bare soil, sand, silt, gravel. Defined by the absence of vegetation without regard to inherent ability to support life. Vegetation, if present, is more widely spaced and scrubby than that in the vegetated classes. Bare land due to agricultural practices are classed as Cultivated Lands. Wet, non vegetated lands not created by spoil depositions are classes as Wetlands.
1.51 Unvegetated non-saline lands, Class #17, are often associated within urban settings.
1.52 Levees and Spoil Depositions, Class #18, are Bare Lands found within spoil compartments.

2.0 Wetlands Class #19
Wetlands are lands where saturation with water is the dominant factor determining soil development and the types of plant and animal communities living in the soil and on its surface (Cowardin *et al.,* 1979). A characteristic feature shared by all wetlands is the soil or substrate that is at least periodically saturated with or covered by water. The upland limit of wetlands is designated as 1) the boundary between land with predominantly hydrophytic cover and land with predominantly mesophytic or xerophytic cover; 2) the boundary between soil that is predominantly hydric and soil that is predominantly non-hydric; or 3) in the case of wetlands without vegetation or soil, the boundary between land that is flooded or saturated at some time during the growing season each year and land that is not (Cowardin *et al.,* 1979). The majority of all wetlands are vegetated and are found on soil.
2.2 Marine/Estuarine Unconsolidated Shore, Class #21 unvegetated flats in the estuarine zone.
2.22 Sand (Salt and Sand flats), Class #23 High reflectance flats. Flats are largely unvegetated with occurrences of plants such as *Monanthocloe littoralis.*
2.23 Mud/organic Flats Class #24 unvegetated mud flats.

2.3 Estuarine Emergent Wetland, Class #26 herbaceous emergent estuarine wetlands both tidal and non-tidal. Hydrology a function of tides, rainfall and marsh management practices. The same vegetation species can be found in all classes of estuarine marsh, but differ in overall composition and dominants.
2.31 Haline Marsh (Salt Marsh), Class #27 is estuarine marsh with an average salinity exceeding 18 ppt.
2.311 Low Salt Marsh, Class #28 permanently flooded, tidally influenced salt marsh dominated by *Spartina alterniflora.*
2.312 High Salt Marsh, Class #29 marsh not normally tidally inundated and within the saline zone. Commonly occurring species in the upper tidal zone include *Salicornia virginica, Batis maritima,* and *Distichlis spicta.*
2.32 Mixohaline (Brackish Marsh), Class #30, is estuarine marsh with an average salinity ranging from 4 ppt - 15 ppt. Brackish Marsh species composition varies considerably from west Galveston Bay to Sabine Lake.
2.321 Low Brackish Marsh, Class #31, is flooded marsh (can be tidally flooded) dominated by *Juncus roemerianus, Distichlis spicta, Spartina patens, Scirpus maritimus.*
2.321 High Brackish Marsh, Class #32, is marsh not inundated and within the brackish zone. Species include *Spartina patens, Juncus roemerianus, Spartina spartinea, Borrichia frutescens.*
2.33 Oligohaline (Intermediate Marsh) Class #33, is estuarine marsh which can be dominated by saline or fresh water species depending on previous hydrologic conditions of site. Average salinity ranges from .5 ppt - 4 ppt. This type of marsh can be the primary wetland type from Trinity river and east Galveston Bay to Louisiana.
2.321 Low Intermediate Marsh, Class #34, is flooded marsh (can be tidally flooded) dominated by *Spartina patens, Alternanthera philoxeroids, Eleochris spp., Scripus olneyi,* and *Scirpus americanus, Phragmites australis, Scirpus californicus, Zizaniopsis miliacea.*

2.322 High Intermediate Marsh, Class #35 is marsh not inundated and within the intermediate zone. Dominant species include *Spartina patens, Spartina Spartinea, Aster spp., Paspalum vaginatum..*
2.343 Salt Prairie, Class #36, are infrequently inundated sites dominated by *Spartina spartinea, Fimberstylus* spp., and *Spartina patens..* Salt Prairie sites are normally bounded by Saline Marsh to Brackish Marsh and Coastal Prairie or Uplands.

2.4 Estuarine Shrub-Scrub, Class #37, Seasonally and tidally flooded shrub-scrub wetlands.
2.41 Deciduous, Class #38, seasonally flooded and occasionally tidally flooded shrub-scrub wetlands dominated by *Iva frutescens* and *Baccharis grandufolia.* Dense herbaceous vegetation such as *Phragmites australis,* and *Scirpus californicus* are spectrally similar to woody vegetation and occasionally included in this class.
2.42 Evergreen, Class #39, Frequently flooded woody vegetation mostly associated with *Avicennia germinas.*
2.43 Mixed, Class #40, mostly deciduous shrubs.

2.7 Palustrine Unconsolidated Shore (Beach, Flat, Bar), Class #49, unvegetated flats in the Palustrine zone.
2.72 Sand (Salt and Sand flats), Class #51, High reflectance flats. Flats are largely unvegetated with occurrences of seasonal vegetation.
2.73 Mud/organic Flats, Class #52, mud flats with occurrences of seasonal vegetation. Vegetation when present is non-persistent and often not detected in the fall when most imagery is captured.
2.8 Palustrine Emergent Wetland, Class #53, herbaceous persistent emergent wetlands (fresh marsh). Salinity ranges between 0 ppt and 0.5 ppt. Hydrology a function of rainfall, episodic flooding and marsh management practices. The same plant species can be found in all classes of Palustrine marsh, but differ in overall composition and dominants.
2.81 Permanent, Class #54 Permanently flooded marsh dominated by obligate wetland and aquatic vegetation. Permanent wetlands are the most diverse wetlands.
2.82 Wet Prairie, Class #55 are infrequently/seasonally inundated sites characterized by mixed associations of wetland and upland vegetation on hydric soil. Hydrology is primarily a function of rainfall. Wet Prairie is spectrally similar to Salt Prairie and often grades into Estuarine Wetlands or Prairie Uplands.

2.9 Palustrine Woody Wetland (Shrub-Scrub/Forested), Class #56, woody freshwater wetlands dominated by facultative to obligate wetland woody vegetation.
2.91 Bottomland/Riparian Woodland, Class #57 Woody wetlands situated along rivers, drainages and creeks. Hydrology as function of episodic flooding and general influence of permanent riparian water source. Common species include, *Carya illinoensis, Fraxinus pennsylvanica, Taxodium distichum, Quarcus aquatica, Salix nigra, Liquidamber styraciflua* etc.
2.92 Swamps Cypress-Tupelo, Class #58, frequently flooded woodlands (Swamps) dominated by *Taxodium distichum, Nyssa aquatica* etc.
2.93 Deciduous Shrub-Scrub (Tallow-Baccharis), Class #59, wet woodlands often found on coastal prairie, spoil and former agricultural sites. On the upper Texas coast these sites are dominated by *Sapium sabiferum, Baccahris grandufolia,* and dense herbaceous stands of vegetation which can be spectrally similar to woody vegetation. Herbaceous vegetation that can be included in this class include *Typha* spp., *Arundo* spp. and *Phragmites australis.*

3.0 WATER AND SUBMERGED LAND, Class #60

3.1 Water (Bottoms and undetectable reefs, aquatic beds or nonpersistent emergent wetlands), Class #61, open water
3.10 Shallow Water, Class #82, shallow water spectrally separated. This class, depending on tidal regime is strongly correlated with mud flats and sand flats.

3.2 Marine/Estuarine Aquatic Bed, Class #69, submerged aquatic vegetation.
3.32 Rooted Vascular (e.g. seagrass), Class #70, submerged seagrass but can include *Rupia* sp., and *Vallisnaria* sp.
3.321 Dense Beds, Class, #71, solid SAV meadows.
3.322 Sparse Beds. Class #72, intermittent and clumped grass beds.

Appendix C

Sample Locations for Galveston Bay NEP Monitoring 1995-1998

YEAR = 1

OBS	SAMPLE	HEXNUM	LAT	LATMIN	LONG	LONGMIN
1	95GB034	248	29	8.8479	95	5.7916
2	95GB033	267	29	9.2862	95	8.9850
3	95GB032	230	29	14.9545	95	0.0174
4	95GB031	231	29	15.0985	94	57.5400
5	95GB030	192	29	19.0006	94	52.3352
6	95GB029	194	29	20.6618	94	45.2893
7	95GB028	193	29	21.4870	94	48.0890
8	95GB027	173	29	23.9746	94	47.4655
9	95GB026	172	29	24.8141	94	52.3801
10	95GB025	171	29	26.9258	94	54.8094
11	95GB024	154	29	27.4358	94	42.4297
12	95GB023	151	29	28.2514	94	56.3255
13	95GB022	156	29	28.4116	94	37.7737
14	95GB021	152	29	29.0966	94	50.7610
15	95GB020	153	29	29.2501	94	49.9598
16	95GB019	155	29	29.5606	94	38.4883
17	95GB018	132	29	30.3162	94	52.6826
18	95GB017	136	29	30.4966	94	36.6161
19	95GB016	131	29	31.6406	94	55.9328
20	95GB015	133	29	31.8360	94	49.1249
21	95GB013	135	29	32.7776	94	38.6668
22	95GB014	129	29	32.7827	95	0.9050
23	95GB012	110	29	34.4741	94	57.5418
24	95GB011	112	29	35.8838	94	50.2542
25	95GB010	113	29	36.0045	94	46.2218
26	95GB009	111	29	37.1051	94	54.8639
27	95GB008	92	29	37.9396	94	49.2375
28	95GB007	94	29	39.0510	94	43.0829
29	95GB006	90	29	39.7697	94	59.3747
30	95GB004	74	29	40.8682	94	43.5562
31	95GB005	93	29	41.0069	94	47.9855
32	95GB002	73	29	44.0336	94	46.0853
33	95GB003	72	29	44.0876	94	50.0368
34	95GB001	54	29	45.1915	94	44.0529

YEAR = 2

OBS	SAMPLE	HEXNUM	LAT	LATMIN	LONG	LONGMIN
35	96GB036	287	29	4.1029	95	11.3837
36	96GB035	267	29	6.7340	95	8.9974
37	96GB034	248	29	9.4502	95	7.3114
38	96GB033	249	29	11.9978	95	2.3030
39	96GB032	251	29	12.8033	94	56.9856
40	96GB031	192	29	20.1031	94	50.1361
41	96GB030	194	29	21.4055	94	44.9460
42	96GB029	193	29	23.2816	94	48.0748
43	96GB028	172	29	24.9549	94	49.9704
44	96GB027	175	29	26.1134	94	42.5560
45	96GB026	173	29	26.2742	94	46.0432
46	96GB024	154	29	27.6717	94	45.3484
47	96GB025	152	29	27.7715	94	51.5044
48	96GB023	153	29	27.8011	94	46.7917
49	96GB022	155	29	29.1696	94	38.7245
50	96GB020	134	29	29.7796	94	42.9565
51	96GB021	132	29	30.0515	94	52.0972
52	96GB019	136	29	30.6413	94	35.9189
53	96GB018	130	29	31.4204	94	59.3299
54	96GB016	137	29	32.1578	94	32.3717
55	96GB017	133	29	32.5659	94	48.7505
56	96GB015	131	29	33.3985	94	54.2706
57	96GB014	112	29	35.7704	94	52.8374
58	96GB013	110	29	37.0188	94	59.2781
59	96GB012	109	29	37.1013	94	59.7926
60	96GB011	92	29	37.1066	94	51.6458
61	96GB010	113	29	37.2101	94	48.4506
62	96GB009	90	29	38.3626	95	0.1753
63	96GB008	111	29	38.4949	94	53.4778
64	96GB007	94	29	38.8912	94	42.8705
65	96GB006	93	29	40.2859	94	48.2854
66	96GB005	72	29	41.5725	94	49.3621
67	96GB004	74	29	43.0508	94	43.0678
68	96GB003	73	29	43.4447	94	47.8967
69	96GB002	69	29	43.9352	95	3.0949
70	96GB001	54	29	45.8448	94	43.7526

YEAR = 3

OBS	SAMPLE	HEXNUM	LAT	LATMIN	LONG	LONGMIN
71	97GB035	268	29	5.4836	95	7.5439
72	97GB034	248	29	9.9765	95	8.3720
73	97GB033	249	29	12.1934	95	2.0764
74	97GB032	230	29	13.5078	95	1.3971
75	97GB031	212	29	18.1444	94	53.2580
76	97GB030	192	29	21.5050	94	53.2201
77	97GB028	193	29	22.9646	94	47.2792
78	97GB029	172	29	22.9788	94	50.4772
79	97GB027	173	29	25.3559	94	48.5820
80	97GB025	154	29	27.0239	94	46.0922
81	97GB026	171	29	27.1564	94	53.9246
82	97GB024	152	29	28.1561	94	50.6355
83	97GB023	153	29	28.4216	94	47.6834
84	97GB022	155	29	30.5651	94	41.7476
85	97GB020	136	29	31.1619	94	39.0834
86	97GB021	132	29	31.4918	94	52.5636
87	97GB018	138	29	32.1761	94	29.8283
88	97GB019	130	29	32.6708	94	57.6700
89	97GB017	137	29	33.2552	94	34.6614
90	97GB016	133	29	33.7850	94	46.0204
91	97GB013	112	29	34.5812	94	52.4227
92	97GB015	131	29	34.6127	94	55.4681
93	97GB014	110	29	34.7503	94	58.7059
94	97GB012	113	29	35.5220	94	48.2011
95	97GB012	111	29	38.0006	94	55.9058
96	97GB011	93	29	38.7204	94	47.7566
97	97GB009	94	29	39.0985	94	42.7940
98	97GB010	90	29	39.3776	94	56.6043
99	97GB008	91	29	39.7687	94	56.4262
100	97GB007	92	29	39.9715	94	51.7181
101	97GB006	95	29	40.1985	94	42.1161
102	97GB005	74	29	41.9529	94	45.3795
103	97GB004	72	29	43.6991	94	50.2551
104	97GB003	73	29	44.2487	94	46.9826
105	97GB002	69	29	44.9764	95	3.7271
106	97GB001	54	29	47.2500	94	43.4011

YEAR = 4

OBS	SAMPLE	HEXNUM	LAT	LATMIN	LONG	LONGMIN
107	98GB038	269	29	9.1636	95	4.1812
108	98GB037	250	29	11.0377	95	0.8158
109	98GB036	230	29	14.0902	95	0.2115
110	98GB035	192	29	18.5749	94	51.3886
111	98GB034	213	29	18.6326	94	49.2659
112	98GB033	193	29	23.6791	94	48.9139
113	98GB032	172	29	24.4825	94	50.8232
114	98GB031	174	29	25.6080	94	45.2458
115	98GB030	173	29	26.1129	94	48.2153
116	98GB029	154	29	27.7736	94	43.3127
117	98GB028	152	29	28.4173	94	51.7237
118	98GB027	153	29	28.7188	94	49.6051
119	98GB026	151	29	29.4688	94	54.4070
120	98GB025	132	29	30.4668	94	49.7909
121	98GB023	133	29	31.6445	94	48.8630
122	98GB024	130	29	31.7094	94	58.6802
123	98GB022	134	29	31.8350	94	42.2278
124	98GB021	136	29	32.3639	94	35.9866
125	98GB020	138	29	32.4836	94	30.2183
126	98GB019	131	29	33.5314	94	54.4885
127	98GB018	110	29	34.5711	94	58.8309
128	98GB017	112	29	34.8262	94	50.8493
129	98GB016	114	29	35.2982	94	45.1932
130	98GB015	109	29	36.7958	95	1.4360
131	98GB014	111	29	37.2993	94	56.0779
132	98GB012	113	29	38.4181	94	48.3092
133	98GB013	92	29	38.4271	94	50.5064
134	98GB011	94	29	39.5136	94	44.2424
135	98GB010	90	29	39.9549	94	57.1431
136	98GB009	93	29	40.1767	94	49.3295
137	98GB008	72	29	42.0808	94	48.8223
138	98GB006	74	29	42.4342	94	41.7737
139	98GB007	68	29	42.5825	95	3.3110
140	98GB005	73	29	44.9522	94	46.0341
141	98GB003	54	29	45.4433	94	45.3388
142	98GB004	69	29	45.8324	95	3.2277
143	98GB002	53	29	45.9521	94	46.7514
144	98GB001	55	29	49.2727	94	40.0763

Appendix D

Power Analysis Calculations

Power analyses are used to determine the probability of getting a significant result as the function of a set of defined test parameters. The power is a function of the unknown parameter values tested, the sample size, and the unknown residual error variance. There are two important uses of power analyses in statistical sampling design. These uses are; 1) prospective— where the analysis is used to predict the most effective sampling design; and 2) retrospective— where we use the power analysis to evaluate the effectiveness of an existing monitoring program. The Galveston Bay Regional Monitoring Program will utilize power analyses in both of the ways identified above. This discussion is intended to describe the use of Power Analysis capability in evaluating design parameters for this program.

As previously defined the power of a statistical test is the probability that an F achieves its α– critical value given a noncentrality parameter related to the hypothesis (SAS, 1994). The noncentrality parameter is zero when the null hypothesis is true, i.e. when the effect size is zero. The noncentrality parameter λ can be factored into three components through the power formula:

$$\lambda=\nu\delta^2 / \sigma^2$$

Where sigma (σ) is the standard error of the residual error in the model. When available the calculated root mean square error (RMSE) from the model is the best estimate for sigma (USEPA, 1987b); Delta (δ) is the raw effect size to be evaluated; and number (n) is the sample size. The power increases with λ, which means it increases with sample size n, and raw effect size δ, and decreases with error variance σ^2.

For purpose of this analysis, the Galveston Bay historical data sets created by Ward & Armstong were utilized to produce a model for estimating parameters of variance in the data sets. The parameters TOC, Ammonia-N, and Total Zinc were selected for detailed power evaluations. They were selected because: they represented a wide selection of variability in the data sets; there was extensive data available; and because they are important parameters for management concerns. Data to generate the design model was limited to data collected from 1986-1990. This should provide a more accurate estimate of the 5-year variability. A 5-year trend estimate is consistent with the stated goals of the monitoring program. Statistical analyses were run for each of the parameters above and the results are displayed as power curves in the following pages. SAS Institute JMP® Statistical Analysis software was used to complete these analyses.

The reduced data sets were input into the JMP **Fit Model** option. This command allows the construction of linear models using a number of complex effects. A **Standard Least Squares** model option was selected for these analyses. Some results of these analyses are shown in the following pages. Tables and plots generated by this program include summary statistics, parameter estimates, effect tests, and analysis table and leverage plot for the multiple regression model, and analysis tables and leverage plots for the effect parameter.

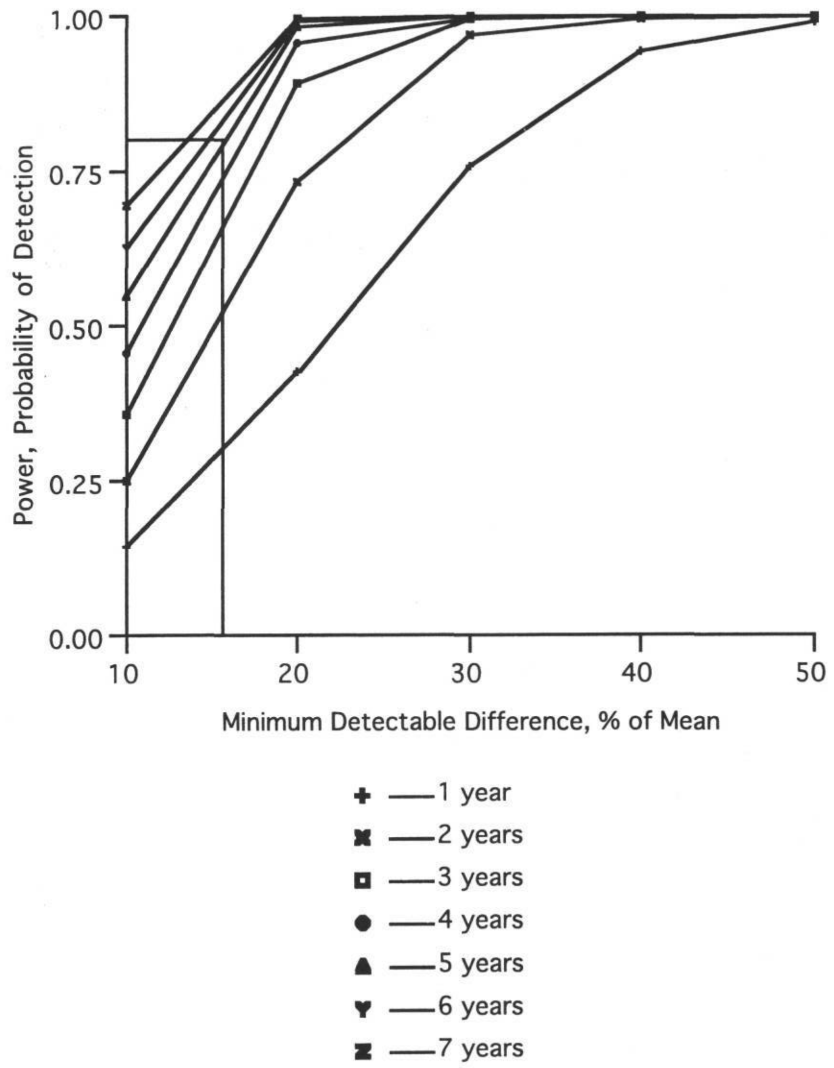
Once the model is generated the **Power Details** command for the effect parameter is selected to access the **Power Details Dialog Box**. In this dialog block, for each of the four variables alpha, n, sigma, and delta, you can fill in a single value, two values, or the start, stop, and increment for a sequence of values. The JMP® power analysis program then calculates power as a function of every combination of alpha, sample size, sigma and delta value specified. It can also calculate the LSN (least significant number) and LSV (least significant value) for each of these combinations of parameters.

A significance level of 0.05 was used for all analyses. JMP® automatically calculates the RMSE as the recommended estimate of sigma, for these analyses the estimate generated from the model was used. For sample size, n, a range from 20 to 140 at increments of 20 were used. With 5 stations per segment and four samples per year (TOC and Ammonia-N), each 20 station increment equals 1 year of sampling. For total zinc sampling will be conducted only once per year. in this example a sample size of 5 is equivalent to a year. The effect size, delta, was calculated and expressed as a percentage of the historical mean (e.g.. mean = 11.7, 10% = 1.17). This was input as a range, usually 10-50%. The results of this analysis are shown in the attached Power Details plots and tables.

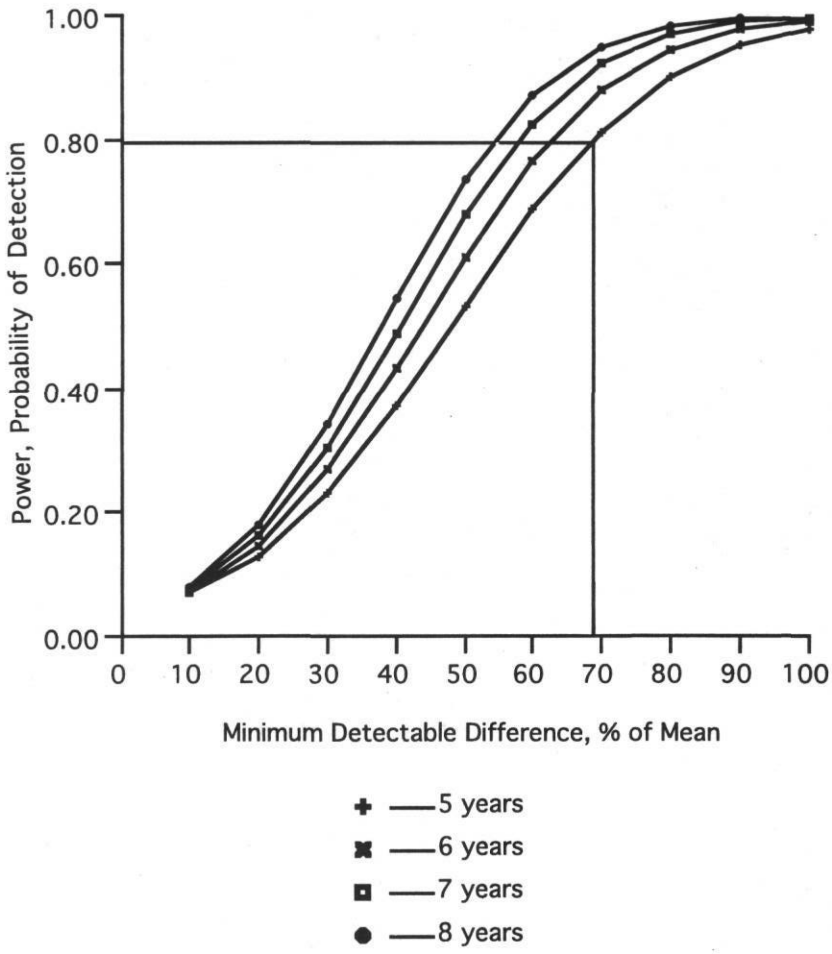
The results of these power tables can be plotted in a number of ways. The following plots express the Power of the F-test vs. the Minimum Detectable Difference that can be achieved, expressed as a percent of the sample mean. Each curve shows the response for a different number of samples, expressed as years (20 samples equals 1 year). For example, the TOC Power Plot on the following page shows that a minimum difference of approximately 16% (from the historical mean of 10.3 mg/l), or 1.65 mg/l, can be detected in the proposed 5-year sampling program. For total zinc the 5-year minimum detection is approximately 18% of the mean. Conversely, the Power Plot for Ammonia-N shows that at best the minimum detectable difference for a five year program, as defined here, would be approximately 70% of the mean.

It should be stated that the values for variance used in these evaluations will provide conservative estimates of detection levels. In calculating the estimates of variance no consideration was given to the effect of between segment or seasonal effects on variance. General estimates of variance such as standard deviation, when looked at on a segment by segment basis, show that variance may be lower or higher than the estimates used in this exercise.

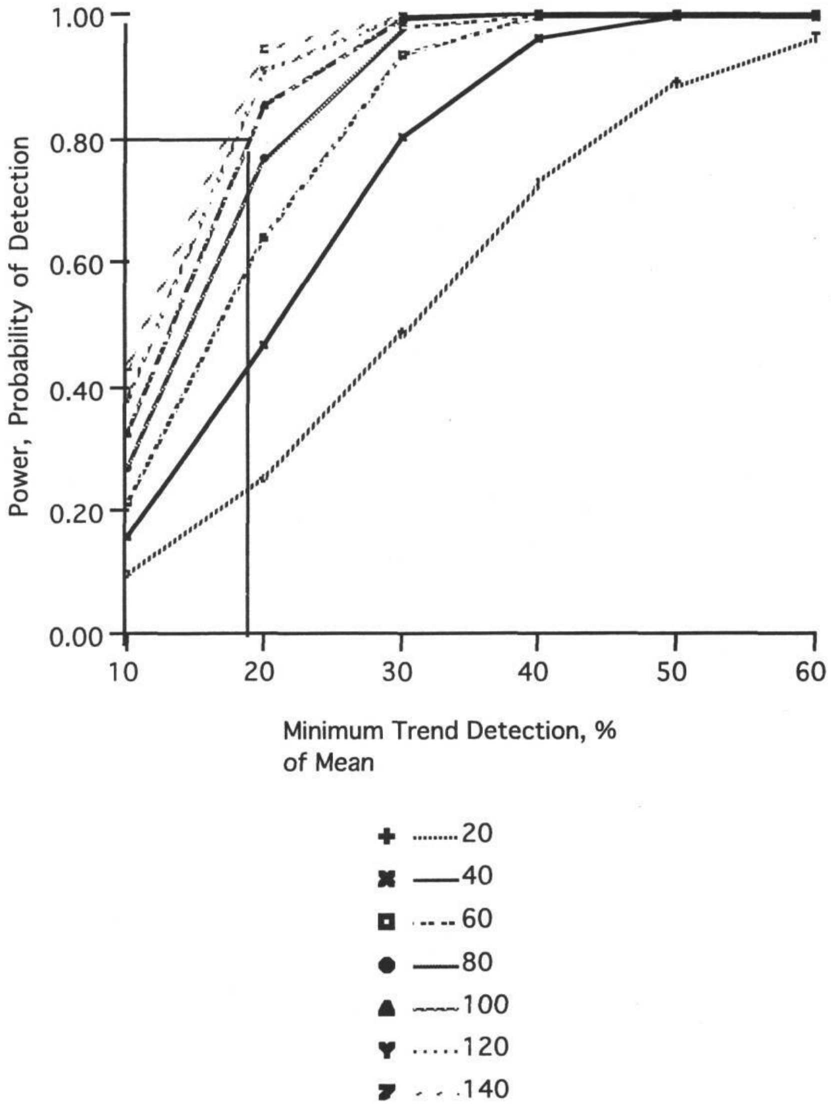
Power of the F-test vs. minimum detectable difference for TOC expressed as a percent of the mean. Design parameters alpha = 0.05, sigma = 4.9, mean = 10.3 mg/l.



Power of the F-test vs. minimum detectable difference for Ammonia-N, expressed as a percent of the mean. Design parameters: alpha = 0.05, sigma = 0.922, mean = 0.38 mg/l.



Power of the F-test vs. minimum detectable difference for total zinc, expressed as a percent of the mean. Design parameters alpha = 0.05, sigma = 24.98, mean = 37.85 mg/l.



Power Analysis Details for TOC, mg/l

Summary of Fit

RSquare	0.397099
RSquare Adj	0.396406
Root Mean Square Error	4.899137
Mean of Response	10.3138
Observations (or Sum Wgts)	872

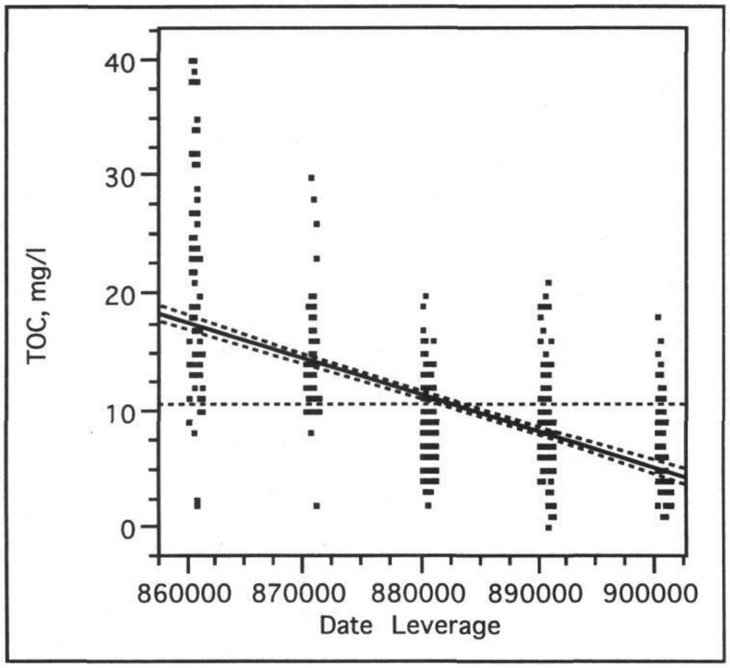
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Date	1	1	13753.462	573.0241	0.0000

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	13753.462	13753.5	573.0241
Error	870	20881.340	24.0	**Prob>F**
C Total	871	34634.803		0.0000

Date



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
13753.462	573.0241	1	0.0000

Power Details for TOC

Test Date

Power

Alpha	Sigma	Delta	Number	Power
0.0500	4.899137	1.03	20	0.1447
0.0500	4.899137	1.03	40	0.2540
0.0500	4.899137	1.03	60	0.3602
0.0500	4.899137	1.03	80	0.4592
0.0500	4.899137	1.03	100	0.5485
0.0500	4.899137	1.03	120	0.6272
0.0500	4.899137	1.03	140	0.6951
0.0500	4.899137	2.06	20	0.4287
0.0500	4.899137	2.06	40	0.7362
0.0500	4.899137	2.06	60	0.8930
0.0500	4.899137	2.06	80	0.9603
0.0500	4.899137	2.06	100	0.9862
0.0500	4.899137	2.06	120	0.9955
0.0500	4.899137	2.06	140	0.9986
0.0500	4.899137	3.09	20	0.7604
0.0500	4.899137	3.09	40	0.9730
0.0500	4.899137	3.09	60	0.9978
0.0500	4.899137	3.09	80	0.9998
0.0500	4.899137	3.09	100	1.0000
0.0500	4.899137	3.09	120	1.0000
0.0500	4.899137	3.09	140	1.0000
0.0500	4.899137	4.12	20	0.9445
0.0500	4.899137	4.12	40	0.9994
0.0500	4.899137	4.12	60	1.0000
0.0500	4.899137	4.12	80	1.0000
0.0500	4.899137	4.12	100	1.0000
0.0500	4.899137	4.12	120	1.0000
0.0500	4.899137	4.12	140	1.0000
0.0500	4.899137	5.15	20	0.9934
0.0500	4.899137	5.15	40	1.0000
0.0500	4.899137	5.15	60	1.0000
0.0500	4.899137	5.15	80	1.0000
0.0500	4.899137	5.15	100	1.0000
0.0500	4.899137	5.15	120	1.0000
0.0500	4.899137	5.15	140	1.0000

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	4.899137	1.03	89.36652
0.0500	4.899137	2.06	24.28933
0.0500	4.899137	3.09	12.36227
0.0500	4.899137	4.12	8.283542
0.0500	4.899137	5.15	6.448558

Power Details for Ammonia-N, mg/l

Summary of Fit

RSquare	0.006138
RSquare Adj	0.005659
Root Mean Square Error	0.922698
Mean of Response	0.382256
Observations (or Sum Wgts)	2076

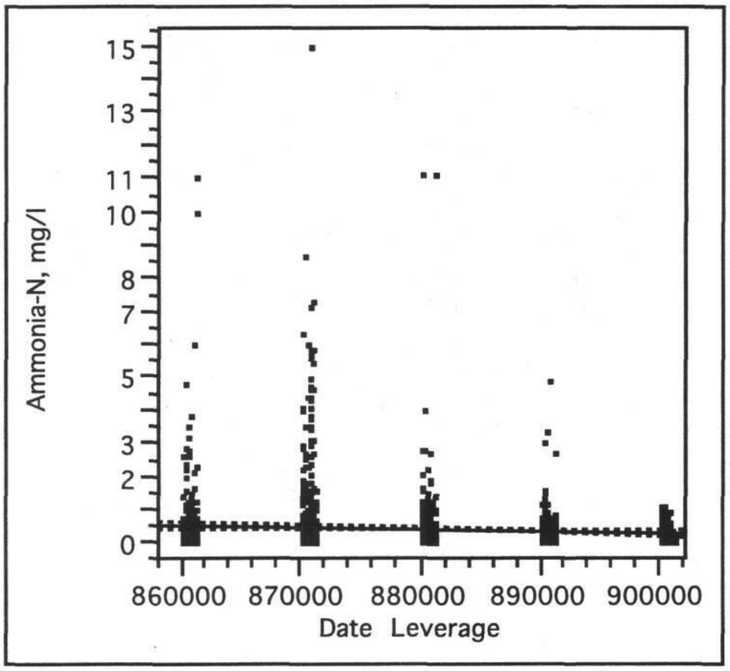
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Date	1	1	10.904908	12.8086	0.0004

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	10.9049	10.9049	12.8086
Error	2074	1765.7435	0.8514	**Prob>F**
C Total	2075	1776.6484		0.0004

Date



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
10.904908	12.8086	1	0.0004

Power Details for Ammonia-N

Test Date

Power

Alpha	Sigma	Delta	Number	Power
0.0500	0.922698	0.038	60	0.0614
0.0500	0.922698	0.038	80	0.0653
0.0500	0.922698	0.038	100	0.0693
0.0500	0.922698	0.038	120	0.0732
0.0500	0.922698	0.038	140	0.0772
0.0500	0.922698	0.038	160	0.0812
0.0500	0.922698	0.038	180	0.0853
0.0500	0.922698	0.038	200	0.0893
0.0500	0.922698	0.076	60	0.0962
0.0500	0.922698	0.076	80	0.1125
0.0500	0.922698	0.076	100	0.1290
0.0500	0.922698	0.076	120	0.1456
0.0500	0.922698	0.076	140	0.1623
0.0500	0.922698	0.076	160	0.1790
0.0500	0.922698	0.076	180	0.1958
0.0500	0.922698	0.076	200	0.2125
0.0500	0.922698	0.114	60	0.1560
0.0500	0.922698	0.114	80	0.1937
0.0500	0.922698	0.114	100	0.2314
0.0500	0.922698	0.114	120	0.2689
0.0500	0.922698	0.114	140	0.3060
0.0500	0.922698	0.114	160	0.3424
0.0500	0.922698	0.114	180	0.3779
0.0500	0.922698	0.114	200	0.4126
0.0500	0.922698	0.152	60	0.2411
0.0500	0.922698	0.152	80	0.3072
0.0500	0.922698	0.152	100	0.3713
0.0500	0.922698	0.152	120	0.4326
0.0500	0.922698	0.152	140	0.4903
0.0500	0.922698	0.152	160	0.5443
0.0500	0.922698	0.152	180	0.5942
0.0500	0.922698	0.152	200	0.6400
0.0500	0.922698	0.19	60	0.3480
0.0500	0.922698	0.19	80	0.4441
0.0500	0.922698	0.19	100	0.5315
0.0500	0.922698	0.19	120	0.6093
0.0500	0.922698	0.19	140	0.6771
0.0500	0.922698	0.19	160	0.7353
0.0500	0.922698	0.19	180	0.7846
0.0500	0.922698	0.19	200	0.8259
0.0500	0.922698	0.228	60	0.4691
0.0500	0.922698	0.228	80	0.5882
0.0500	0.922698	0.228	100	0.6868
0.0500	0.922698	0.228	120	0.7657
0.0500	0.922698	0.228	140	0.8273
0.0500	0.922698	0.228	160	0.8742
0.0500	0.922698	0.228	180	0.9094
0.0500	0.922698	0.228	200	0.9354
0.0500	0.922698	0.266	60	0.5933

0.0500	0.922698	0.266	80	0.7213
0.0500	0.922698	0.266	100	0.8145
0.0500	0.922698	0.266	120	0.8794
0.0500	0.922698	0.266	140	0.9232
0.0500	0.922698	0.266	160	0.9520
0.0500	0.922698	0.266	180	0.9704
0.0500	0.922698	0.266	200	0.9820
0.0500	0.922698	0.304	60	0.7087
0.0500	0.922698	0.304	80	0.8291
0.0500	0.922698	0.304	100	0.9036
0.0500	0.922698	0.304	120	0.9473
0.0500	0.922698	0.304	140	0.9720
0.0500	0.922698	0.304	160	0.9854
0.0500	0.922698	0.304	180	0.9926
0.0500	0.922698	0.304	200	0.9963
0.0500	0.922698	0.342	60	0.8060
0.0500	0.922698	0.342	80	0.9056
0.0500	0.922698	0.342	100	0.9564
0.0500	0.922698	0.342	120	0.9806
0.0500	0.922698	0.342	140	0.9917
0.0500	0.922698	0.342	160	0.9965
0.0500	0.922698	0.342	180	0.9986
0.0500	0.922698	0.342	200	0.9994
0.0500	0.922698	0.38	60	0.8804
0.0500	0.922698	0.38	80	0.9533
0.0500	0.922698	0.38	100	0.9829
0.0500	0.922698	0.38	120	0.9940
0.0500	0.922698	0.38	140	0.9980
0.0500	0.922698	0.38	160	0.9994
0.0500	0.922698	0.38	180	0.9998
0.0500	0.922698	0.38	200	0.9999

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	0.922698	0.038	2267.316
0.0500	0.922698	0.076	568.65
0.0500	0.922698	0.114	254.0887
0.0500	0.922698	0.152	143.9998
0.0500	0.922698	0.19	93.05255
0.0500	0.922698	0.228	65.38597
0.0500	0.922698	0.266	48.71252
0.0500	0.922698	0.304	37.8994
0.0500	0.922698	0.342	30.49442
0.0500	0.922698	0.38	25.20591

Power Details for Total Zinc, mg/l

Summary of Fit

RSquare	0.169099
RSquare Adj	0.120223
Root Mean Square Error	24.98504
Mean of Response	37.85263
Observations (or Sum Wgts)	19

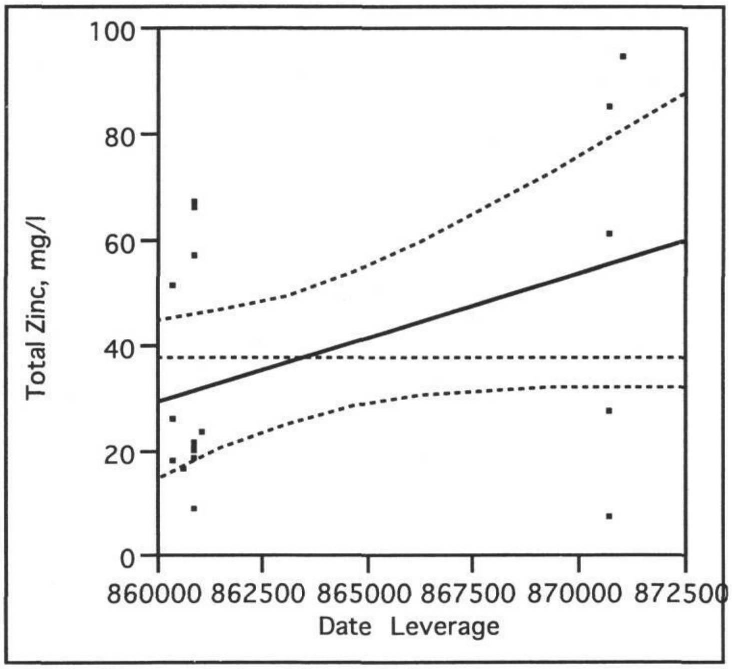
Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
Date	1	1	2159.7411	3.4597	0.0803

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	2159.741	2159.74	3.4597
Error	17	10612.286	624.25	**Prob>F**
C Total	18	12772.027		0.0803

Date



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
2159.7411	3.4597	1	0.0803

Power Details

Test Date

Power

Alpha	Sigma	Delta	Number	Power
0.0500	24.98504	11.39	15	0.3730
0.0500	24.98504	11.39	20	0.4879
0.0500	24.98504	11.39	25	0.5885
0.0500	24.98504	11.39	30	0.6739
0.0500	24.98504	11.39	35	0.7447
0.0500	24.98504	11.39	40	0.8022
0.0500	24.98504	15.18	15	0.5861
0.0500	24.98504	15.18	20	0.7291
0.0500	24.98504	15.18	25	0.8287
0.0500	24.98504	15.18	30	0.8947
0.0500	24.98504	15.18	35	0.9367
0.0500	24.98504	15.18	40	0.9628
0.0500	24.98504	18.97	15	0.7758
0.0500	24.98504	18.97	20	0.8943
0.0500	24.98504	18.97	25	0.9529
0.0500	24.98504	18.97	30	0.9799
0.0500	24.98504	18.97	35	0.9918
0.0500	24.98504	18.97	40	0.9967
0.0500	24.98504	22.76	15	0.9028
0.0500	24.98504	22.76	20	0.9705
0.0500	24.98504	22.76	25	0.9917
0.0500	24.98504	22.76	30	0.9978
0.0500	24.98504	22.76	35	0.9995
0.0500	24.98504	22.76	40	0.9999

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	24.98504	11.39	21.06918
0.0500	24.98504	15.18	13.09589
0.0500	24.98504	18.97	9.460748
0.0500	24.98504	22.76	7.52478

Appendix E

Appendix E. Criteria Values, Used To Characterize Degraded Sediments (from Long and Morgan, 1990). NA= Not Available.

PAH (ppb)	10% Effect Concentration [1]	Median Effect Concentration [2]
Acenaphthene	150	650
Acenaphthylene	NA	NA
Anthracene	85	960
Benzo(a)anthracene	230	1600
Benzo(a)pyrene	400	2500
Benzo(b)fluoranthene	NA	NA
Benzo(e)pyrene	400	2500
Benzo(g,h,i,)perylene	NA	NA
Benzo(k)fluoranthene	NA	NA
Biphenyl	NA	NA
Chrysene	400	2800
C1, C2, C3, C4 Chrysene	400	2800
Dibenzo(a,h)anthracene	60	260
Dibenzothio	NA	NA
C1,C2, C3 -dibenzothio	NA	NA
Fluoranthene	600	3600
C1-fluoranthpyrene	NA	NA
Fluorene	35	640
C1, C2, C3 fluorene	35	640
Naphthalene	340	2100
C1, C2, C3, C4- naphthalene	340	2100
Perylene	NA	NA
Phenanthrene	225	1380
C1, C2, C3, C4-phenanthrene	225	1380
Pyrene	350	2200
1,2,3-c,d-pyrene	NA	NA
1-methylnaphthalene	NA	NA
2-methylnaphthalene	NA	NA
2,3,5- Trimethylnaphthalene	NA	NA
2,6- Dinethylnaphthalene	NA	NA
1- methylphenanthrene	NA	NA
High Molecular Wt. PAH's	NA	NA
Low Molecular Wt. PAH's	NA	NA
Total PAH's	4000	3500
PCB's (ppb)		
Total PCB's	400	NA
Individual congerners	25	NA
Pesticides (ppb)		
2,4'DDD	2.0	20
4,4'DDD	2.0	20
2,4'DDE	2.0	20
4,4'DDE	2.0	20
2,4'DDT	2.0	20
4,4'DDT	2.0	20

Appendix E. Criteria Values Used To Characterize Degraded Sediments (from Long and Morgan, 1990). NA= Not Available. (cont'd).

	10% Effect Concentration [1]	**Median Effect Concentration [2]**
Aldrin	NA	NA
alpha-BHC	NA	NA
beta-BHC	NA	NA
delta-BHC	NA	NA
alpha- chlordane	.5	6
gamma- chlordane	.5	6
Dieldrin	.02	8
Endrin	.02	45
Heptachlor	NA	NA
Heptachlor epoxide	NA	NA
Methoxychlor	NA	NA
Lindane	NA	NA
Toxaphene	NA	NA
Malathion	NA	AN
Parathion	NA	NA
Diazinon	NA	NA
Endosulfan	NA	NA
Mirex	NA	NA
Total BHCs	NA	NA
Metals (ppm)		
Aluminum	NA	NA
Antimony	2	25
Arsenic	33	85
Cadmium	5	9
Chromium	80	145
Copper	70	390
Iron	NA	NA
Lead	35	110
Manganese	NA	NA
Mercury	.15	1
Nickel	30	50
Selenium	NA	NA
Silver	1	2
Tin	1	3
Zinc	120	270

[1] Concentration where biological effects occurred 10% of the time.

[2] Median concentration for effects to occur.